SOIL MANAGEMENT FOR VEGETABLE PRODUCTION ON RECLAIMED PHOSPHATIC CLAYS

By

RAFAEL ANTONIO JEREZ Y GOMEZ

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1994

This work is dedicated to my daughters Geraldine Alexandra and Aída Esperanza; to my wife Nancy Altagracia; to my parents Francisco Antonio and Aída Luz, and to my brothers and sisters Máximo, Luly, Isleida, César, and Iris.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to my major advisor, Dr. Edward A. Hanlon, and Dr. Jerry B. Sartain, cochairman of my graduate committee, for their support, encouragement, guidance and friendship during the realization of this study. I owe a great debt of gratitude to them for their support in my field and glasshouse studies. I am also indebted to Dr. George J. Hochmuth, another member of my committee, with whom I worked closely, and who provided me with glasshouse and materials for my studies, as well as guidance and support. I am also grateful to the other members of my supervisory committee, Drs. Randall B. Brown, Donald A. Graetz, and Dorota Z. Haman, for their suggestions, support and encouragement. I want to thank the members of the graduate committee also for editorial and scientific comments to this dissertation.

During my field studies I had a great deal of support from the management and staff of MLAR/DP in Bartow, FL, and I express my sincere gratitude to them. I am thankful to Mr. James Stricker, who was instrumental in procuring the funds from the funding agencies for this research, FIPR and the Polk County Board of Commissioners. My sincere thanks go to Dr. David Shibles, Mr. Charles Riddle, Mr. David

Haffer, and Mr. Jerry Hicks for their help and support during my field research. I also want to thank Land Restoration Corporation for their assistance on my research.

Special gratitude is due to my former research mates in the project, Ms. Brunilda Luciano-Lugo and Mr. Paul Bueker, who helped me complete part of the field work.

I also want to thank the University of Florida Analytical Research Laboratory staff, especially Mr. Jorge González, for their assistance in conducting most of the chemical analyses for my research. I also extend my gratitude to Mr. Larry Schwandes, who helped me conduct chemical analyses.

I would like to thank the members of the "incubation" room (408 Newell), Shailesh Patel, Hayriye Ibrikçi, and Len Scinto, for their friendship, support, and understanding during some difficult times. Shailesh and Orlando Díaz shared many good things with me, and I appreciate that very dearly. I want to thank Fernando and Sonia Cabrera, and Luis and Raisa Guerrero for their friendship, and Dr. Laura Newman, for her friendship, support, and spiritual guidance.

Most of all, I would like to thank my wife, Nancy, and my daughters Geraldine and Aída, who supported me emotionally in moments of need. I am grateful for the encouragement and support provided by my parents, Francisco and Aída, and my siblings Máximo, Luly, Isleida, César, and Iris.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS iii

LIST OF TABLES vii

LIST OF FIGURES ix

ABSTRACT xi

CHAPTER 1 INTRODUCTION 1

Site Description 1
Origin 3
Chemical and Physical Characteristics of Phosphatic Clay 7
Regional Effect of Declining Phosphatic and Citrus Industries 10
Problems for Agricultural Production 11
Economic Importance of Vegetable Production . . . 12
Objectives 13

CHAPTER 2 SOIL CHARACTERIZATION AND SNAP BEAN PRODUCTION ON FERTILIZED PHOSPHATIC CLAYS 15

Introduction 15
Materials and Methods 17
Field Survey 17
Glasshouse Experiment 18
Results and Discussion 20
Characterization of CPC 20
Pot Experiment Results 26
Conclusions 32

CHAPTER 3 SNAP BEAN PRODUCTION ON SLUDGE-AMENDED PHOSPHATIC CLAYS 33

Introduction 33
Materials and Methods 36
Results and Discussion 40
Residual Effect of Sludge Application on Soil Composition 41
Effect of Sludge Application on Plant Growth and Yield 45

Effect of Sludge Application on Plant Nutrition 48
Conclusions 56

CHAPTER 4 SWEET CORN PRODUCTION ON SLUDGE-AMENDED PHOSPHATIC CLAYS 58

Introduction 58
Materials and Methods 60
Results and Discussion 63
Effect on Soil Composition 63
Sweet Corn Yield Measurements 68
Sweet Corn Tissue Analysis 70
Conclusions 72

CHAPTER 5 WATER MANAGEMENT FOR SEEDBED PREPARATION AND SEED COVER FOR VEGETABLE STAND ESTABLISHMENT ON PHOSPHATIC CLAYS 74

Introduction 74
Materials and Methods 81
Field Operations 81
Reliefmeter 82
Roughness Index 83
Growth and Yield Analyses 86
Results and Discussion 87
Surface Roughness 87
Growth and Yield Analyses 90
Conclusions 97

CHAPTER 6 SUMMARY AND CONCLUSIONS 98

Recommendations for Follow Up 100

LITERATURE CITED 102

BIOGRAPHICAL SKETCH 113

LIST OF TABLES

Table 2-1. Physical and Chemical Characteristics of Phosphatic Clays 21

Table 2-2. Results of Mehlich-3 Extraction on Phosphatic Clay from IMC for N, P, and K Study in Spring and Fall, 1986 27

Table 2-3. Selected Foliar Nutrient Concentrations at Bloom, for N, P, and K Glasshouse Study on Phosphatic Clay from IMC, for Spring and Fall, 1986 29

Table 2-4. Average Dry weight Yield of Snap Bean Plants Grown on Phosphatic Clay from IMC at Different Rates of N, P, and K, for Spring and Fall, 1986 30

Table 3-1. Elemental Concentration of Municipal Sewage Sludge from Tampa, Spring 1986 37

Table 3-2. Response of Chemical Concentrations of Phosphatic Clay to Sludge Rates at the End of Three Seasons of Snap Bean Production in a Glasshouse Experiment, 1986-1987 46

Table 3-3. Response of Growth Parameters of Snap Bean Grown on Phosphatic Clay from IMC to Sludge Rates During Three Seasons in a Glasshouse Experiment, 1986-1987 49

Table 3-4. Response of Foliar Nutrient Concentrations of Snap Bean Grown on Phosphatic Clay from IMC to Sludge Rates During a Three Season-Glasshouse Experiment, 1986-1987 51

Table 3-5. Nutrient Sufficiency Levels for Most Recently Matured Leaves at First Blooming of Snap Bean 52

Table 3-6. Average Foliar Concentrations of N, Ca, Mn, and Zn, by Season, of Snap Bean Grown on Municipal Sewage Sludge-Amended Phosphatic Clay, 1986-19878 53

Table 4-1. Results of Mehlich-3 Extraction on Municipal Sewage Sludge-Amended Phosphatic Clay on a Five-Season Sweet Corn Experiment at Agrico, 1986-1989 67

Table 4-2. Leaf Tissue, Early Tasseling Stage, Nutrient Concentration of Sweet Corn Grown on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico, 1987-1989. 71

LIST OF FIGURES

Figure 2-1. Moisture Release Curve of Phosphatic Clays at both IMC and Agrico Sites 23

Figure 2-2. Langmuir Adsorption Isotherm for Cd Adsorption to Phosphatic Clay 25

Figure 3-1. Changes in Organic Carbon in a Three Year Glasshouse Experiment, Growing Snap Bean on Sewage Sludge-Amended Phosphatic Clay, 1986-1988 43

Figure 3-2. Effect of MSS on Pod Yield (DM) of Snap Bean Grown on Phosphatic Clay from IMC in a Three-Season Glasshouse Study 50

Figure 4-1. Changes in Organic Carbon in a Five-Season Experiment, Growing Sweet Corn on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico Site, 1986-1989 64

Figure 4-2. Yield of Sweet Corn Cultivars, by Season, on a Five-Season Field Study on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico, 1986-1989. LSD Comparison is Valid Within Season, Over Cultivars. Only "Merit" was Harvested in Spring 1989, and no Comparison is Applicable 69

Figure 5-1. Example of Pin Height Measurement, Regression Line Describing the Average Bed Surface, and Horizontal Line Simulating an Ideal Bed Surface in Cucumber Field Study at IMC, 1988 84

Figure 5-2. Regressions of Amount of Irrigation Water on Surface Roughness Index, R_f on a Cucumber Field Study at IMC Site, 1988-1989 89

Figure 5-3. Effect of Seed Cover on Emergence of Cucumber, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Covers . 91

Figure 5-4. Effect of Seed Cover on Cucumber Duration to Emerge, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Covers . 93

Figure 5-5. Effect of Planting Method on Cucumber Yield, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Covers . . 95

Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

SOIL MANAGEMENT FOR VEGETABLE PRODUCTION ON RECLAIMED PHOSPHATIC CLAYS

By

Rafael Antonio Jerez y Gómez

April 1994

Chairman: Dr. E.A. Hanlon
Cochair: Dr. J.B. Sartain
Major Department: Soil and Water Science

Phosphate mining has produced approximately 50 000 ha of colloidal phosphatic clay (CPC) settling ponds in Polk County, FL. The CPC may have potential for vegetable production. A series of glasshouse and field experiments were conducted to assess (1) macronutrient requirements of 'Sprite' snap bean (Phaseolus vulgaris L.) grown on CPC in a glasshouse, and of sweet corn (Zea mays L. var. rugosa) grown on CPC under field conditions; and (2) effects of wetting and drying cycles on CPC surface roughness, and of planting methods on stand establishment and yield of cucumber (Cucumis sativus L.).

Snap bean received 0 and 35 mg N kg^{-1} soil; 0, 11, and 21 mg P kg^{-1}; and 0, 19, and 39 mg K kg^{-1}. A second study with snap bean used municipal sewage sludge (MSS) at 0, 50,

100, and 200 g kg^{-1}. Cumulatively, 0, 26, 52, and 104 Mg MSS ha^{-1} were added in the 5-season sweet corn study. In the surface roughness study, one, two, or three wetting/drying cycles were applied to hasten clod mellowing.

Snap bean yield increased with N or MSS rate. The major nutrient contribution from MSS was N. A mathematical model accurately predicted soil organic carbon (OC) levels throughout the 3-yr study. Sweet corn yield averaged 5.6 Mg ha^{-1}, showing no response to MSS rate. Of four sweet corn cultivars, 'Merit' consistently produced highest yields. More rapid OC decay was observed in the field than in the glasshouse study, and the decomposition model accurately predicted that. Soil surface roughness decreased as wet-and-dry cycles increased. Transplanting produced highest yields of cucumber (50 Mg ha^{-1}), compared to seed covers. Use of screened CPC as a seed cover was not effective.

It was shown that CPC can produce high quality vegetable crops, with minimum additional nutrients, and with reduced tillage using the mellowing process. This system can alleviate a problem of disposal of excess MSS, with no damage to crops or CPC.

CHAPTER 1
INTRODUCTION

The state of Florida is the largest domestic producer of phosphate, accounting for an average of 75% of the total annual U.S. production (McHardy, 1983). Within the state, Polk County is the largest phosphate producing area, containing 57 000 ha of mined land. Phosphate mining activities in the state also occur in the counties of Hamilton, Hardee, Hillsboro, and Manatee (Woods, 1986).

Polk County is located in the Central Florida Peninsular pebble phosphate area. Phosphate mining operations in the 1960s replaced the orange industry as the backbone of the economy of Polk County. Mining operations have been moving gradually towards the south and east of the county, in search of deposits more economical to extract.

Site Description

Field experiments were conducted on land leased from both Agrico Chemical Company (Agrico, Sect. 9, T32S, R23E), Mulberry, and International Minerals and Chemicals Corporation (IMC, Sect. 32, T30S, R24E), Bartow. The region enjoys a subtropical humid climate with mean annual temperature at Wauchula, the closest meteorological station, of 22 C and mean annual precipitation of 1350 mm, 60% of

which occurs between June and September (NOAA, 1988). A daily maximum rainfall of approximately 200 mm, and rainfall intensities of greater than 100 mm/h have been recorded. The estimated evapotranspiration rates for the site range from 46 mm per month in December to 112 mm per month in May. Average daily relative humidity ranges from 66 to 76%, and average dewpoint temperature ranges from 12 C in January to 23 C in August.

Colloidal phosphatic clay (CPC) is rejected as slurry from the beneficiation processing of mined ore, and deposited in settling ponds (Barwood, 1982). Approximately 50 000 ha of settling ponds now exist on phosphate mined land in Polk County. This area is estimated to increase to about 80 000 ha by the turn of the century (Stricker, 1988). The unreclaimed land, including settling ponds, tailings, and disturbed overburden, has been of great concern to residents and administrators of the county for some time (Lamont et al., 1975), due to its objectionable appearance (Woods, 1986), and its reduced value (Stricker, 1988; Newborn, 1986).

Payne Creek, its unnamed tributaries, and the Alafia River are the aquatic systems in the vicinity of the studies discussed in this publication. Payne Creek is a relatively shallow stream located east of the Agrico site. The creek's floodplain has been subject to hydrologic change resulting from sedimentation, ditching of its tributaries for

agricultural operations, and more recently, elimination of some tributaries as a result of mining. Ditches and berms that border the mined areas keep runoff from draining into Payne Creek.

The soils of the surrounding areas (Ford et al., 1990) are dominated by Smyrna (sandy, siliceous, hyperthermic Aeric Haplaquods) and Myakka fine sand (sandy, siliceous, hyperthermic Aeric Haplaquods). Most of the area surrounding the sites is covered with pasture, of which bahiagrass (Paspalum notatum L.) is the dominant species. There are also abandoned citrus (Citrus sp.) groves, logged pine (Pinus sp.) plantations, and small patches of oak (Quercus sp.) woodland. The land was originally native flatwoods vegetation before citrus and pasture were planted, and some remnant flatwoods areas remain.

Wetlands in this area include several isolated marshes and a central forested wetland that drains into Payne Creek. The marshes have formed in depressions in the flatwoods, in which Floridana soils (loamy, siliceous, hyperthermic Arenic Argiaquolls) can be found, and the dominant vegetation consists of maidencane (Panicum hemitomon L.), juncus (Juncus effusus L.), and pickerelweed (Pontederia sp.).

Origin

The Florida Peninsula was formed in a series of recurring processes of recession and intrusion of the ocean into the mainland. The base of the peninsula is constituted

of limestone, itself overlain almost completely by a geologic formation rich in phosphates and subdivided into several other formations. The Hawthorn formation, deposited on Tampa and Ocala limestone, is the parent material from which hard rock phosphate on the north and pebble phosphate deposits at the center of the peninsula were derived.

The pebble phosphate beds found in Central Florida are residual deposits from the Pliocene epoch (Vondrasek, 1982; Bloomquist, 1982), when the products of the erosion of the Hawthorn formation were deposited in a broad delta of a stream that opened southward into the ocean. These pebble phosphate beds comprise the so-called Bone Valley Formation. Phosphate deposits are the result of a process of mixing and compaction of phosphate, sand, and clay in equal parts into a "matrix."

The Hawthorn formation is 65 to 130 m thick, whereas the Bone Valley formation averages a thickness of 3 to 4 m, and it is overlain by loose sandy materials from marine terraces of the Pleistocene epoch. The major geologic structure of the region is the Peninsular Arch which forms the backbone of the Florida Peninsula striking S 35° E. The mining district falls into the geomorphic province known as the Polk Upland (White, 1970), which is flat and covered with permeable sands ranging in depth from 10 to 30 m.

Florida's "grey gold," as the phosphates were called, were discovered by two boar hunters in 1881 (Grace, 1954).

Polk County, about 83 km long by 67 km wide (Bloomquist, 1982), became the phosphate center of Florida surpassing Dunnellon, Marion County, the original world phosphate leader (Burnett, 1976).

Mining in Central Florida began as a pick and shovel operation. Since World War II, the demand for phosphate as an inorganic fertilizer, both at the national and international level, has grown. Its demand for other industrial uses such as food preservatives, toothpaste, animal feeds, and vitamin and mineral capsules, has also increased. This demand has led to a tremendous increase in mining operations, producing over one Tg of ore annually, thereby generating massive quantities of dilute CPC (Pittman and Sweeney, 1983).

The top of the phosphate matrix lies approximately 3.0 to 15.5 m below the earth's surface. Phosphate mining is accomplished through the method of area strip mining. Through this method, large electrical draglines remove the overburden, including topsoil that is usually used later in site reclamation.

The matrix is then removed and placed in a pit, where high-pressure water jets (1.45 MPa) disperse it, creating a phosphate ore slurry, which is pumped via a pipeline to a beneficiation plant. Wet screening and floatation processes are used to extract the phosphate rock (Zellars-Williams, 1978), resulting in three types of materials that reflect

the physical composition of the ore: a) Coarse phosphate rock, which goes into inventory piles; b) a mixture of sand and fine phosphate, known as "feed," and c) fine clay suspended in water, often called "slimes." The feed undergoes further processing in several steps involving mild chemical additives to separate the fine phosphate from the sand. The resulting sand tailings are pumped into existing mine cavities. The phosphate is conveyed to inventory piles.

Very large volumes of water (approximately 30 m^3 Mg^{-1} phosphate) are needed in the beneficiation process, thus exceeding tremendously the volume of material extracted from the mine cavities. For this reason, impounded holding areas are constructed, generally on land already mined, to retain the water-clay fraction (only about 2 to 5% solids suspended in water), to let the clay settle, hence the name settling ponds. These deep ponds (each covering 120 to 320 ha) are surrounded by arcuate spoil piles rising as much as 6 to 9 m above natural grade.

The small average particle size of the clays slows the settling process. Moreover, the hydrophilic nature of the clays further contributes to slowing water release from the mixture. As the clays settle, clear water is left at the surface (about 80% of the initial volume used), and is recycled to the beneficiation plant. Settling ponds occupy significant land areas (about two-thirds of the mined land).

Chemical and Physical Characteristics of Phosphatic Clay

The clay size fraction is mainly dominated by montmorillonite, but includes attapulgite, kaolinite, and illite, with lesser amounts of other minerals such as quartz and residual phosphates (Environmental Service Center, 1984; Lamont et al., 1975). The high specific surface area and water holding capacity of the two major minerals slow the rate of consolidation, such that these materials reach 12 to 18% solids within 6 to 24 months. Thereafter, additional dewatering is controlled by evapotranspiration. A typical settling pond may take up to 29 years to completely solidify (Bloomquist, 1982; Pittman and Sweeney, 1983). If dewatering is left to natural processes, these settling ponds require 10 to 15 years to reach 40 to 50% solids at the surface, a suitable condition for agricultural development. Below the first 10 cm, the water content is much higher and a paste persists for long periods.

Phosphatic clays have a plasticity index ranging from 70 to 150, with a very plastic and very sticky consistency when wet (Barwood, 1982; Bloomquist, 1982; Bromwell, 1982), firm consistency when moist, and extremely hard consistency when dry, developing cracks as large as 10 cm wide and 25 cm deep. This cracking poses a management problem for intensive agriculture.

The high colloidal content of CPCs gives them excellent nutrient and moisture retention capacities. These

attributes make CPC highly suitable for agriculture. These materials, occupying 50% of the mined lands, constitute an acceptable medium for plant growth with higher fertility than the native sandy soils generally found in Central Florida (Zellars-Williams, 1978). Furthermore, CPC shows a high capacity for sorption of metals. These soils are the product of the evaporation of slurry deposits, and thus are flat, and very poorly drained, classified as Hydraquents, clayey, when they still hold standing water. When they have been allowed to dry, they are classified as Haplaquents, clayey (Ford et al., 1990).

Organic matter is often the reservoir for plant nutrients, such as N. However, CPC, as with most mined soils, is low in soil organic matter (SOM) content (EcoImpact, 1980). Initially, the reclaimed soils contain little SOM, if any. However, there are good reasons to believe that this problem can be corrected with time. Build-up of SOM occurs relatively quickly in the early stages, and then more slowly, until it stabilizes. The establishment of vegetation results in litter and root material deposition. As a consequence, SOM builds up and promotes formation of favorable soil structure. The native soils of the area are low in SOM. It has been found that in 10 to 20 years a reclaimed soil can achieve SOM levels comparable to those of native soils (EcoImpact, 1980). The

addition of sewage sludge and other organic amendments can accelerate SOM build-up.

Since July 1975, Florida law has made it mandatory that all lands disturbed by phosphate mining be restored (Hochmuth et al., 1987). As a consequence, the Florida Institute of Phosphate Research (FIPR) was established and became responsible for research on CPC (Pittman and Sweeney, 1983). Agricultural use of the land was a major object (Garlanger and Fuleihan, 1983). The natural high water holding capacity (which would reduce irrigation needs) and fertility of these clays should make crop production on them an attractive economic venture, if some management problems were solved.

Crop production uses of reclaimed lands have been minimal, except for some citrus grove establishment. Reclamation of settling ponds is expensive and time consuming. Blue and Mislevy (1982) obtained an increase in the drying rate of settling ponds through N fertilization of naturally invading plant species and introduced grasses, with overseeding of a cool-season legume.

Mislevy and Blue (1981a) studied the effect of CPC and sewage sludge-amended sand tailings on tropical forage grasses. In 1976 and 1978, they found highest dry matter yields when sand tailings were amended with a mixture of CPC and sewage sludge or topsoil. In 1978, they found no differences. The same researchers (1981b) also studied the

effects of the same amendments on four summer annual grasses and found that highest yields of forage dry matter and grain were obtained when the sand tailings were amended with CPC plus topsoil.

Mislevy et al. (1981) found that five tropical legumes developed better under unamended sand or when the sand was amended with waste CPC.

González and Sartain (1985), using different sand-clay mixtures on five different vegetable species, found that the plants performed better with the sand-clay mixtures than with the sand tailings. Million et al. (1987) conducted a similar study and obtained similar results, with higher yields at 2:1 sand:clay ratio (SCR); however, at higher SCR, tillage workability increased.

Regional Effect of Declining Phosphate Mining and Citrus Industries

The phosphate industry, which has been operating in the region for over a century, together with the citrus industry, have been a major economic support for Central Florida. However, weather changes experienced in recent years are forcing the citrus growers southward, shunning the freezes. This phenomenon has caused a dramatic economic setback for the region.

It is estimated that at the current rate of mining, the phosphate reserves of Polk County will be largely depleted by the turn of the century (Stricker, 1987), and the industry will move farther south, towards more economical

operations. That move will have an adverse impact on the county's economy (Environmental Service Center, 1984). The county will have lost approximately 10 000 jobs and an estimated $2.5 million in ad valorem tax revenues during this period.

Reclamation of these clay areas for production of agricultural crops may improve their aesthetic value, simultaneously contributing to the county's economy (Hochmuth et al., 1987; Stricker, 1988). It is imperative that these lands be put back into production of high-value crops that will generate sources of jobs to replace the loss of the industry departure.

The Polk County Mined Lands Agricultural Research/Demonstration Project (MLAR/DP) is a cooperative effort involving the University of Florida's Institute of Food and Agricultural Sciences (IFAS), the Polk County Board of Commissioners, FIPR, and the Polk Soil and Water Conservation District. The project was established in October 1985 (Hochmuth et al., 1987; Woods, 1986) to conduct practical research to define proper management of the CPC for intensive agricultural production.

Problems for Agricultural Production

The main objectives of the MLAR/DP are to (a) carry out research on the production of agronomic and horticultural crops (such as small grains, forages, and vegetables) on the CPC, and (b) demonstrate the feasibility of commercial

production of those crops through the management of this complex system.

There are several problems in the management of these soils of suspected high fertility, among which is their trafficability after a rainfall or irrigation application. The high stickiness and plasticity precludes field access when wet, thus hampering timely agricultural operations. Moisture is excessive during the spring, and drainage must be provided.

Tillage operations form large clods that persist over periods of time not suitable for acceptable stand establishment. The disintegration of those large clods would take excessive number of machinery passes. This problem can be overcome by breaking down the clods with the addition of irrigation or rainfall, or by tillage.

Air filled pore spaces in the soil matrix are assumed to be scarce, which poses problems for aeration of the roots. Cracking of the surface alleviates this problem. The effect of organic matter addition to these soils is uncertain, although it is expected to promote structure and enhance pore development.

Economic Importance of Vegetable Production

Florida is the second largest producer of vegetables in the United States. The total area dedicated to vegetable production in Florida exceeds the 156 000 ha, with an on-

farm value of $1.66 billion (Florida Agricultural Statistics, 1992).

As Florida's urban areas continue to grow, there is an increasing pressure placed upon the limited water supply. Vegetable growers, in the future, can expect to be allocated decreasing amounts of water for crop production, so they must become more efficient in irrigation management.

Rahmani et al. (1990) conducted a market window analysis for five vegetable crops, namely cabbage (Brassica oleracea L. Capitata group), sweet corn (Zea mays L. var. rugosa Bonaf.), cucumber (Cucumis sativus L.), green peppers (Capsicum annuum var. annuum L.), and squash (Cucurbita pepo L.) for the region. The evaluation of the economic feasibility of producing vegetables on CPC is difficult. There are no available data on cost of production estimates for commercial vegetable operations on these soils. Rahmani et al. (1990) estimated that cabbage, white sweet corn, cucumbers, and crookneck squash show a potential economical viability for production on reclaimed phosphatic clays in Polk County.

Objectives

In view of the feasibility studies conducted in the area for vegetable crop production, and the problems posed by these CPC, several experiments were undertaken to meet the following objectives:

1. Assess the need for N, P, and K from inorganic sources, or dominantly N from municipal sewage sludge (MSS) in pots from IMC CPC on snap beans grown in a glasshouse.
2. Determine the effects of MSS on yield and on the uptake of nutrients and heavy metals by sweet corn grown on reclaimed CPC under field conditions.
3. Test effects of overhead irrigation levels on CPC surface roughness, and seed covering effects on stand establishment under field conditions.

CHAPTER 2
SOIL CHARACTERIZATION AND SNAP BEAN PRODUCTION ON FERTILIZED PHOSPHATIC CLAYS

Introduction

The mining of phosphates from central Florida lands leaves behind large areas of settling ponds, which may be developed for intensive agriculture (Wood, 1986). Vegetables offer this alternative, since Polk County is located within one of the main winter vegetable producing areas of Florida.

Snap bean (Phaseolus vulgaris L.) has been one of the leading truck crops grown in Florida (Hills et al., 1953). This species will not tolerate frost, but will develop at relatively low temperatures. The climate of the area is favorable for snap bean.

Although snap bean is a leguminous plant, its nitrogen (N) fixation is inefficient (Hills et al., 1953; Nicholaides et al., 1985); thus, snap bean has responded positively to N application (Asif and Greig, 1972; Nicholaides et al., 1985). Cosgrove et al. (1985) found that snap bean performed best when the main source of N was NO_3, especially after blooming. Although NH_4 can provide some N for snap bean, they recommended that its levels should never exceed those of NO_3.

Nicholaides et al. (1985) found that the supplement of phosphorus (P) and potassium (K) to a Bradson gravelly loam (clayey, oxidic, mesic Typic Hapludult) promoted rapid seedling growth and snap bean yield increase of 50%. Snap bean was planted at a density of 66 000 plants ha^{-1}. The Bradson soil is low in Mehlich I-extractable P and K (8 and 70 kg ha^{-1}, respectively). Asif and Greig (1972) planted 71 730 snap bean plants ha^{-1} on a Sarpy fine sandy loam (fine-loamy, mixed, mesic Typic Udipsamment), with initially high available P (96 kg ha^{-1}, no extraction method provided) and exchangeable K (455 kg ha^{-1}). They found a yield reduction up to 20% when P and K were supplied at rates of 48 and 93 kg ha^{-1}, respectively. The highest yield (3.83 Mg ha^{-1}) was obtained by supplying 134 kg N ha^{-1}, compared to the average Florida yield of 2.9 Mg ha^{-1} (Florida Agricultural Statistics, 1992).

To define CPC at the two sites, a field survey was conducted. This information was considered essential to all management of future fertility work on CPC.

A greenhouse experiment was conducted to help make decisions for future field work. The objective of this study was to determine the effect of different rates of N, P, and K on the growth and yield of snap bean grown on CPC in a glasshouse.

Materials and Methods

Field Survey

Characterization of clays at the IMC and Agrico sites was accomplished using samples from four locations at each site, and four depths (0 to 5, 7.5 to 10, 23 to 25, and 28 to 30-cm). Bulk density and water content were determined in 1988 using the core method (Blake and Hartge, 1986).

Particle size distribution was determined by the pipette method (Gee and Bauder, 1986). Cation exchange capacity was determined by the summation method (Thomas, 1982). Moisture release was determined by subjecting the samples to pressures of 0.4, 2, 3, 4.5, 6, 8, 10, 15, 20, 33.3, and 1500 kPa.

Adsorption isotherms were obtained by equilibrating, in a 50-mL centrifuge tube, 0.25 g of the sieved CPC with 10 mL of 0.01 M $CaCl_2$ containing 2.5, 5, 10, 20, 40, 80, and 100 mg Cd L^{-1}, following the procedure used by John (1972). The suspension was shaken for 24 hours at a temperature of 25 C. Afterwards, the tubes were centrifuged at 12 000 rpm for 10 minutes, followed by filtration of the supernatant liquid through a Whatman filter paper #42. The amount of dissolved Cd was subsequently determined by atomic absorption spectrophotometry (AA). The amount of metal adsorbed was calculated from the difference between the amount added and that recovered in the equilibration solution. This procedure was completed in triplicate and averaged.

Glasshouse Experiment

A pot experiment was conducted in a glasshouse at Gainesville, FL. The study was carried out in two consecutive seasons in 1986, starting on 31 March and 2 September.

A bulk sample of CPC (IMC) was collected when at about 50% water content. The CPC was loaded into a truck using a large front loader. The loader operator removed the CPC from the surface to a depth of over 2 m. Approximately 30-kg lots were passed through a 1-cm sieve, and the resulting material was mixed thoroughly, before dividing into pots. Twelve seeds of 'Sprite' snap bean were planted 1 to 1.5 cm deep in two rows, in plastic pots containing 7 kg of the CPC. Percentage stand establishment was recorded and seedlings were thinned to eight per pot at 14 days after planting (DAP). The plants were kept within a temperature range of 24 to 34 C.

Treatments were arranged in a completely randomized design in a 2 x 3 x 3 complete factorial with four repetitions. The factors under study and their levels were N (0 and 67 kg ha^{-1}), P (0, 20, and 39 kg ha^{-1}), and K (0, 37, and 75 kg ha^{-1}). The fertilizer sources were reagent-grade ammonium nitrate, monocalcium phosphate, and potassium chloride, each dissolved in water to obtain the required rates. Fertilizer rates were applied at a depth of 2.5 cm with a syringe, and then covered with CPC, before planting.

Phosphatic clay samples were taken from the pots before fertilization. The samples were air-dried and ground to pass through a 1-mm sieve; these CPC samples were analyzed using the Mehlich-3 (M-3; Mehlich, 1984) extractant for P, K, Ca, Mg, Zn, Mn, and Cu using an inductively coupled argon plasma spectrophotometer (ICAP). The pH of CPC and the wide range of nutrients that M-3 can extract were decisive factors in the choice of this extractant. Organic carbon was determined by oxidation of 0.5 M $K_2Cr_2O_7$ in the presence of H_2SO_4 using a modified Walkley-Black procedure (Hanlon and DeVore, 1989), and pH was determined on a 2:1 (water:clay) mixture.

Tissue from the most recently matured leaf was collected at blooming (approximately the R1 growth stage) in both seasons, and pots were thinned to 3 plants, 30 DAP. Tissue samples were oven-dried at 70 C to constant weight. Each entire sample was then ground to pass a 1-mm screen, using a stainless steel Wiley mill. Total Kjeldahl N (TKN; Bremner and Mulvaney, 1982) was determined on the samples. One-gram samples were weighed and dry-ashed, and digested for P, K, Ca, Mg, Zn, Mn, Cu, and Fe using the ICAP (Hanlon and DeVore, 1989). At harvest, 55 DAP, pod length, pod width, pod marketable weight and number, plant height, and plant numbers were measured.

Initially, M-3 was developed for nutrient status assessment in the soil (Mehlich, 1984), especially when soil

reaction is neutral and alkaline. Subsequently, several researchers have reported the use of M-3 to extract heavy metals in the soils. Mulchi et al. (1987, 1991), extracted Mn, Zn, Cu, Fe, Pb, Ni, and Cd. Concurrently and independently, Sims et al. (1991), and Xiu et al. (1991) used M-3 to extract Zn, Cu, Cd, Ni, and Pb.

All statistical analyses were performed at $P \leq 0.05$ level of significance using Statistical Analysis System (SAS, 1988) procedures. The data were subjected to analysis of variance using the GLM procedure and, when appropriate, regression analysis; comparisons were performed using the LSMEANS option.

Results and Discussion

Characterization of CPC

The CPC bulk density (Table 2-1) was low, compared to a 1.25 to 1.45 Mg m^{-3} for unmined mineral soils in the area (Ford et al., 1990). This low bulk density is a factor of the water content at the moment of sampling (58%). Soil core samples were taken just prior to the formation of cracks on the surface. At that point, soil water was high compared to unmined surrounding sandy soils. Particle size analysis showed that over 90% of the soil was in the clay fraction.

Organic carbon (Table 2-1) was highly variable (CV = 38%) in the field, which suggests differential rate of surface drying, since standing water slows organic matter

Table 2-1. Physical and Chemical Characteristics of Phosphatic Clays.

Bulk Density	Water Content	Organic Carbon	Clay Content	CEC	BS
$Mg\ m^{-3}$	$m^3\ m^{-3}$	$g\ kg^{-1}$	$g\ kg^{-1}$	$cmol\ kg^{-1}$	%
0.91±0.02†	0.58±0.02	17.3±1.6	915±21	83.2±1.2	78±0.3

† Standard error of mean. Number of observations = 32.

decomposition. An increase in OC content with time should be expected as vegetation grows. In any case, low OC values were expected due to the incipient development of the CPC and the processes of formation of these soils (settling ponds). Plants have grown on these soils and contributed to the soil OC, especially at root depth. Organic carbon at the surface was 17 g kg^{-1} (CV = 38%), whereas below 15 cm it was only 8 g kg^{-1} (CV = 18%). Increased OC is expected to improve physical characteristics of CPC by forming stable clay-organo complexes (Clapp et al., 1986) that should facilitate the formation of soil structures and improve soil aeration and drainage. Organic matter applied and incorporated to CPC will accelerate this process.

The CPC contained from 65 to 68% soil water at field capacity, pressures between 10 and 33 kPa (Fig. 2-1). Water content tended to increase as depth increased, but the difference was not statistically significant, since particle size throughout the profile was homogeneous.

At a pressure of 1500 kPa (permanent wilting point), the volumetric water content of CPC was 33% (Fig. 2-1). The upper 18 cm of Myakka fine sand, a soil commonly found in the local area, retains approximately 3% water at the permanent wilting (Ford et al., 1990). The volume of water theoretically available to plants from CPC was about 35%, whereas only about 6% (Ford et al., 1990) has been found plant-available from the Myakka soil. This characteristic

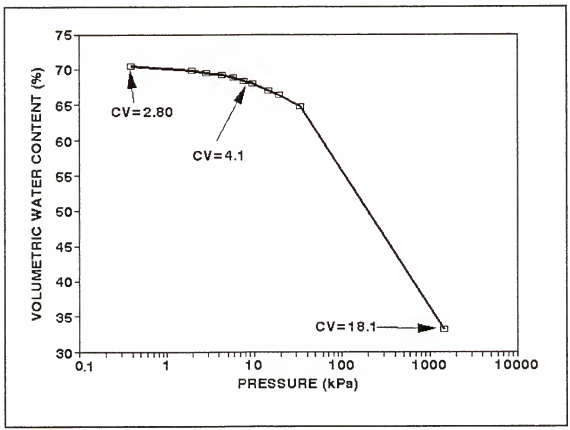


Figure 2-1. Moisture Release Curve of Phosphatic Clays at both IMC and Agrico Sites.

suggests a lower frequency of irrigation for CPC than for adjacent sandy soils.

The the soil-pH by the 2:1 water-to-soil method was 6.9 at IMC and 7.3 at Agrico, suitable for a variety of crops. Solubility of heavy metals is low at these pH levels. Sauerbeck (1991) found that changing pH from near-neutral to slightly acid increased heavy metals availability. The high CEC found on CPC (Table 2-1) in comparison with surrounding unmined soils (Ford et al., 1990) is also important in decreasing heavy metals availability.

Hawkins (1973) found that the predominant clay minerals in these soils are smectites, illite, palygorskite, and kaolinite, with other minerals such as quartz and apatites. As a result of the high clay content and its mineralogy, these soils exhibited a high affinity for cations in the environment, in agreement with findings of Cd sorption by montmorillonite (Petruzzelli et al., 1985). The adsorption isotherm of CPC (Fig. 2-2) showed a Langmuir adsorption maximum (b) of 4.896 mg g^{-1} soil, suggesting that the CPC was able to adsorb substantial amounts of Cd. Cadmium is one of the elements that sorbs the least to clay surfaces (Farrah et al., 1980). The study of Cd adsorption enabled inferences to be drawn about the adsorption of other metals to CPC, especially the heavy metals of most concern, such as Pb, Cd, Ni, and Cr. From the high adsorption capacity found for Cd, CPC can be expected to retain Pb, Ni, and possibly

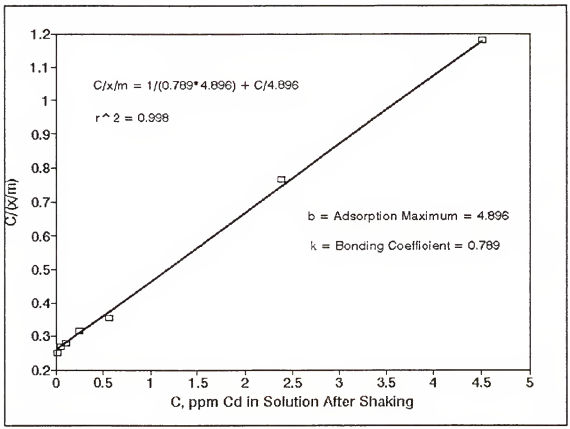


Figure 2-2. Langmuir Adsorption Isotherm for Cd Adsorption to Phosphatic Clays.

Cr. González et al. (1992) found that CPC suppressed Cd uptake by alfalfa (Medicago sativa L.) grown on MSS-amended sand tailings. If excessive loading of these elements occurs, there exists the danger of later release.

The M-3-extractable nutrient concentration of CPC (Table 2-2) was well above the critical values for most crops (Mehlich, 1984) except for Mn. High concentrations of M-3 extractable suggest that the bulk of the crop nutrient requirements for these elements may be supplied by the soil, with no supplemental fertilizer addition. The low concentration of Cd, Ni, Cr, and Pb (Table 2-2) suggested that no phytotoxicity is to be expected (Gough et al., 1979).

Pot Experiment Results

As field-moist soil was screened (prior to placement into pots), elongated structures resembling strudels formed. These structures subsequently disintegrated as the pot soil surface dried, effectively smoothing out the soil surface, so-called "maturing" or "mellowing." The same phenomenon was expected to have occurred at other depths, as the soil dried. The observation of the "mellowing" process in this pot experiment suggested that surface clods could be degraded or reduced by inducing mellowing using a series of wetting and drying cycles. This concept was explored in a subsequent experiment, presented in Chapter 5. Organic carbon of the CPC used in the pot was low (6 g kg^{-1},

Table 2-2. Results of Mehlich-3 Extraction on Phosphatic Clay from IMC for N, P, and K Study in Spring and Fall, 1986.

Element	Concentration	Critical value[†]
	mg dm^{-3}	
P	540±9[‡]	30
K	360±9	47
Ca	5 180±54	N/A[§]
Mg	2 050±36	61
Fe	244±1.3	N/A
Mn	2.8±0.2	4
Zn	4.7±0.2	1
Cu	3.7±0.2	0.5
Cd	0.18[¶]	N/A
Ni	0.36[¶]	N/A
Cr	0.09[¶]	N/A
Pb	0.35[¶]	N/A

[†] North Carolina State Interpretation.
[‡] Mean ± standard error of mean. Number of observations = 32.
[§] Not applicable.
[¶] Standard error of mean < 0.01.

CV = 36%), when compared with surrounding unmined mineral soils having a range of 12 to 30 g kg^{-1} (Ford et al., 1990), and CPC samples from the settling pond surface (Table 2-1). This relatively low value may have been due to the method of collection of the CPC.

Foliar nutrient concentration at blooming (Table 2-3) was not affected by increasing rates of N, P, or K, which suggests that the supply by the soil was so high that the additional amount supplied by the fertilizer did not contribute to plant nutrient uptake. Nitrogen concentration was below the suficiency range given by Hochmuth et al. (1991). However, no visual symptoms developed to suggest that a deficiency of any of these elements occurred.

Other foliar nutrient concentrations of snap bean at blooming (Table 2-3) were within the adequate ranges for this species at that stage (Hochmuth et al., 1991). Both Mn and Cu foliar nutrient concentrations were close to the lower extreme of the sufficiency range, but still within it. Only Mn was expected to be deficient, based on M-3 soil test results.

Fertilizer rates, mainly those of N, had an effect on all growth parameters measured (Table 2-4), except seedling emergence, which was 67% (±1.6). No interaction of fertilizer rates and season was found.

The aerial biomass of the plant (Table 2-4) increased when N was supplied. Plant height averaged 19.4 (CV = 31%).

Table 2-3. Selected Foliar Nutrient Concentrations of Snap Bean at Bloom, for N, P, and K Glasshouse Study on Phosphatic Clay from IMC, for Spring and Fall, 1986.

Nutrient	Concentration	Sufficiency Range[†]
	g kg^{-1}	
N	18±0.3[‡]	30-40
P	3±0.05	2.5-4.5
K	26±0.4	20-30
Ca	161±0.4	8-15
Mg	10±0.1	2.6-4.5
	mg kg^{-1}	
Fe	88±2.9	25-200
Mn	22±0.7	20-100
Zn	26±0.4	20-40
Cu	5±0.1	5-10
B	28±0.2	15-40

[†] From Hochmuth et al. (1991).
[‡] Mean ± standard error of mean.
Number of observations = 144.

Table 2-4. Average Dry Weight Yield of Snap Bean Plants Grown on Phosphatic Clay from IMC at Different Rates of N, P, and K, for Spring and Fall, 1986.

	N Rate, mg kg^{-1}	
Parameter	0	35
	g $plant^{-1}$	
Pod	2.64±0.09†b‡	4.33±0.16a
Biomass	8.10±0.46b	11.19±0.45a

† Mean ± standard error of the mean.
Number of observations = 72.
‡ Values followed by the same letter in a row are not different at P = 0.05.

Pod and biomass yield (Table 2-4) increased when N was applied to the CPC. Pod yield increased 60% over the control, whereas biomass yield increased 40%. These findings suggest that the soil provided adequate amounts of P and K for snap bean growth. Moreover, they support the hypothesis that N is deficient in these soils.

These findings agree with those of a field experiment of snap bean plants conducted by Peck et al. (1989) on a Lima silt loam (fine-loamy, mixed, mesic Glossoboric Hapludalf). Those researchers reported a pod yield increasefrom 1.5 Mg ha^{-1} (DW) without N applied, to 1.8 Mg ha^{-1} at 80 kg N ha^{-1}, using $(NH_4)_2SO_4$.

In another experiment, Nicholaides et al. (1985) found that fresh snap bean yield had a quadratic response to N, and increased from 7.3 Mg ha^{-1} to a maximum of 9.5 Mg ha^{-1}, at a rate of 168 kg N ha^{-1}. They found that pod yield increased linearly up to 9.5 Mg ha^{-1}, at 68 kg K ha^{-1}, and also showed a response to P, with a maximum of 10.2 Mg ha^{-1}, at a rate of 14 kg P ha^{-1}. That experiment was conducted on a highly weathered soil of low fertility.

Furthermore, Asif and Greig (1972) found that pod yield increased up to 7.7 Mg ha^{-1}, at a rate of 130 kg N ha^{-1}. In contrast with Nicholaides et al. (1985), they found that pod yield decreased when P or K was added.

In the present study, N produced a yield increase both in pods and biomass. No effect on N plant tissue

concentration in the plants was found. This phenomenon suggests that N addition increased the total amount of N taken up by the plants; however, since N addition also produced an increase in biomass, a dilution effect took place, leaving the plant concentration about the same.

Conclusions

Both the soil and foliar chemical results suggest that the CPC provided snap bean with adequate nutrient amounts for growth, with the exception of N. Crop growth during both seasons reinforced this hypothesis, since only the application of N had an effect on snap bean yield.

A neutral to slightly alkaline pH might have affected the availability of some elements. No disorders were observed in this glasshouse experiment. pH could also play an important role in the availability of heavy metals, which these soils contained in trace amounts. The presence of Cd, Ni, Pb, and Cr in CPC was not shown to be detrimental to snap bean growth and yield.

CHAPTER 3
SNAP BEAN PRODUCTION ON SLUDGE-AMENDED PHOSPHATIC CLAYS

Introduction

The application of sewage sludge on agricultural lands is beneficial to crops as a source of organic matter and nutrients, especially N, P, and micronutrients. Utilization of sewage sludge on agricultural lands has been favored over other types of disposal. Scarcity of landfill sites, increasing costs of cnemical fertilizers, high energy requirements for sludge incineration, and increasing public awareness of the need to protect our environment have directed disposal toward agricultural solutions. However sewage sludges, especially those from industrial areas, may contain elements which are non-essential or even potentially toxic (Akhter, 1990; Hue, 1988; Soon et al., 1980). In some cases, the application of sewage sludge has produced an enrichment of Hg, Zn, Cu, Se, Pb, Cr, and Ni in the soil (Andersson and Nilsson, 1972), and subsequently has led to increased metal loading in the food chain (Akhter, 1990; Soon et al., 1980).

Available data (Akhter, 1990; Sommers et al., 1987) show that a 'typical' sewage sludge does not exist with respect to metal content, varying according to origin and

pretreatment processes to which the sludge has been subjected. Those conditions, coupled with the chemical and mineralogical properties of the amended soils, and the rates of application, affect the bioavailability of the sludge-borne metals (Hue et al., 1988).

Organic matter, whose main constituents are organic carbon (OC) and N, is the most important active component of sewage sludge. Organic matter tends to undergo rapid decomposition in most agricultural soils; thus, the study of OC and N transformation in the soil is essential in understanding the behavior of sewage sludge.

Moorhead et al. (1987), working with fresh anaerobically digested sludge of water hyacinth biomass, mixed with Arenic Paleudults, used first order kinetics to describe decomposition rates, evaluated by CO_2 evolution and ^{15}N mineralization. They found that the decomposition rate of digested materials was about 1/3 of that for fresh material. Similar decomposition rates were found for other substrates by Miller (1974) and Tester et al. (1977). They found that fresh plant biomass always released more C as CO_2 than digested biomass. Since the decomposition rate of plant residues and sludges in soil is governed by the proportion of the various C fractions, the overall rate may be described best by more complex models than simple first-order kinetics.

Multistage decomposition sequences have been used to describe OC decomposition in soil (Miller et al., 1974; Moorhead et al., 1987). Each stage is thought to represent the sequential ease of C constituent decomposition, i.e. soluble sugars and starch, cellulose, hemicellulose, and lignin. These researchers have modeled OC decomposition using digested and fresh biomass, not municipal sewage sludge - a more completely decomposed material.

Most OC decomposition studies are based on CO_2 evolution during incubation (Hsieh et al., 1981; Moorhead et al., 1987). Hsieh (1981) found that both total and organic N and C are lost during aerobic digestion of sewage sludge.

In most cases, the application of sewage sludge lowers the soil pH (Cheung and Wong, 1983; Hue, 1988). At the same time, the increase in OC often complexes potentially toxic elements, improves water relations, and improves the conditions for root penetration of higher plants (Holtzclaw et al., 1978).

Wong et al. (1981) found that the application of sewage sludge, at rates as low as 5.4 Mg ha^{-1}, induced retarded seed germination of Chinese radish (Raphanus sativus var. longipinnatus L.) and decreased root elongation by 80%. Wolt (1985) found that the N concentration of corn ear leaf tissue varied with year after application. Kelling et al. (1977) found an increase in N and P in plant tissue due to sewage sludge, which induced an increase in sorghum yield, with evident residual benefits for at least 3 years.

The results reported in Chapter 2 indicated that CPC provided sufficient nutrients for snap bean production and that N was the only deficient element. As a consequence, a second glasshouse experiment was conducted to help make future decisions on N applications for field work to follow on these CPC. The objective of this study was to determine the effect of different rates of municipal sewage sludge (MSS) on the growth, yield, and foliar nutrient concentration of snap bean grown on CPC in a glasshouse setting. A secondary objective was to investigate the residual effects of MSS on subsequent plantings of snap bean, and on the soil elemental composition.

Materials and Methods

A pot experiment was conducted in a glasshouse provided by the Horticultural Sciences Department of the University of Florida, in Gainesville. The study was conducted during three consecutive seasons, starting on 31 March and 2 September 1986, and 13 April 1987.

Recently reclaimed CPC from an IMC site was screened to pass a 10-mm sieve. A heat-dried (15 to 20% moisture), anaerobically digested class I MSS (Table 3-1) from the city of Tampa was thoroughly mixed with screened CPC, using an electric-driven cement mixer. The MSS was added to the CPC to obtain 0, 50, 100, and 200 g MSS kg^{-1} CPC by dry weight.

The experiment was a completely randomized design (CRD) with eight replicates. Twenty seeds of 'Sprite' snap bean

Table 3-1. Elemental Concentration of Municipal Sewage Sludge from Tampa, Spring 1986.

	Source		
	AWTP[†]	Dry Ashing[‡]	EPA[§]
Element	Total Concentration		
	g kg^{-1}		
N	70	59	N/A[¶]
P	17	23	N/A
K	1	1	N/A
Ca	-	15	N/A
Mg	3	12	N/A
	mg kg^{-1}		
Zn	1 230	1 190	7 500
Mn	77	180	N/A
Cu	499	615	4 300
Fe	13 100	9 700	N/A
B	-	34	N/A
Cd	15	16	85
Pb	123	154	840
Ni	37	40	420

[†] Data provided by Advanced Water Treatment Plant.
[‡] Ashed at 500 C for all elements, except for N, which was determined by micro-Kjeldahl. Means of 5 observations.
[§] U.S. EPA (1993) Ceiling concentrations.
[¶] Not applicable.

were planted (1 to 1.5 cm deep) in rows 15 cm apart, in plastic pots, each containing 10 kg of the corresponding mixture for the particular treatment. Percentage stand establishment was recorded and seedlings were thinned to twelve per pot upon establishment. The plants were kept in a temperature range of 24 to 34 C. After each season, the CPC/MSS within each particular treatment were mixed together for replanting for the subsequent season.

Samples of each mixture were air-dried and ground to pass through a 1-mm sieve. These samples were extracted with M-3 and analyzed for P, K, Ca, Mg, Zn, Mn, Cu, Cd, and Pb using the ICAP; Ni and Cr were extracted using the same solution and were analyzed using an atomic absorption spectrophotometer (AA). Organic carbon was determined by oxidation of 0.5 M $K_2Cr_2O_7$ in the presence of H_2SO_4 using the Walkley-Black procedure (Hanlon and DeVore, 1989), and pH determined on a 2:1 (water:clay) mixture. Nitrogen was determined on the CPC/MSS samples using the micro-Kjeldahl procedure.

Tissue from the most recently matured leaf was collected at blooming (approximately the R1 growth stage), and oven-dried at 70 C to constant weight. Each entire sample was then ground to pass a 1-mm screen, using a stainless steel Wiley mill. The micro-Kjeldahl procedure was used to determine N concentration. One-gram samples were weighed, dry-ashed, and digested for elemental chemical

analysis (Hanlon and DeVore, 1989). Analysis included P, K, Ca, Mg, Zn, Mn, Cu, Fe, Pb, Cd, and B, using the ICAP, and Ni and Cr using the AA. Low heavy metal content found in the tissue led to the modification of the ratio (tissue:solution = 1:50) recommended in the extraction method, and use of a ratio of 1:10, but only for the last season.

At harvest, pod length, width, marketable weight and number, plant height, and stand counts were measured. Also, days to maturity, and biomass yield at both blooming and harvest were recorded. From these data, biomass and pod growth rates were calculated. Biomass and its rates are indices of the light-harvesting ability of the crop canopy (Scully and Wallace, 1990). Harvest Index (HI = pod yield/biomass) measures assimilate distribution, whereas Biomass Growth Rate (BGR = biomass/days to maturity) and Economic Growth Rate (EGR = pod yield/days to maturity) relate the length of the crop cycle to biomass and pod yield.

All statistical analyses were performed at $P = 0.05$ level of significance using the Statistical Analysis System (SAS, 1988) procedures. The data were subjected to analysis of variance (ANOVA), with single degree of freedom contrasts, using the GLM procedure and, when appropriate, regression analysis.

Results and Discussion

Analytical results of the MSS from the city of Tampa (Table 3-1) showed a material with moderate N concentration but low in K. The phosphorus content was low when compared with the CPC concentration (Table 2-2). The chemical properties of the MSS make this a source mainly of N, which is the nutrient needed for snap bean growth on the CPC. One of the major concerns in the application of MSS is the leaching of nitrates into the ground water and its flow into the surrounding water bodies. In Central Florida, nitrate movement would be a major concern, due to the high density of lakes in the region. However, column studies conducted on the CPC have shown a low rate of permeability that slows leaching through the profile considerably. The same low rate of permeability (as low as 5.8E-10 cm s^{-1}, as calculated by Ardaman and Associates, 1982) that hinders field operations over a long period after rainfall serves as a deterrent to pollutant transmission through the profile. Furthermore, the application of MSS would increase the organic carbon (OC) content of the CPC, with suspected improvement of tilth and chemical processes.

Heavy metal (Cu, Zn, Cd, Ni, Pb, and Cr) extractable concentrations were low, and pH was neutral, which suggests that heavy metal release would be low (Table 3-1).

Residual Effect of Sludge Application on Soil Composition

Properties of the CPC sampled 20 months after MSS application (three croppings with snap bean) showed a lasting effect of sludge as a soil amendment.

Organic carbon decomposition. Organic carbon content of the soil increased linearly with increasing MSS. Such an increase was expected, since OC is a major component of MSS (35 ± 2%, by DW).

Some models describing decomposition of soil organic matter (SOM) assume the rate of decomposition, k, to be constant. Experimental evidence has proven this assumption incorrect (Moorhead et al., 1987). The models have defined a 'coefficient of humification', h, equal to the fraction of added material still present after 1 yr. Both h and k depend on the types of organic material.

The application of organic residues to soils leaves two fairly independent OM pools in most soils: a smaller labile fraction consisting of plant residues and their 'humified' turnover products; and a larger fraction of more stable OM.

Plant residues show a complex and varied chemical composition, thus a single constant k is not appropriate. There is an initial rapid breakdown of sugars, proteins and cellulose, leaving more resistant material, such as waxes and lignin. Furthermore, the easily decomposable materials are partly resynthesized into microbial products which decay at an intermediate rate.

Janssen (1984) derived an equation to quantify the process of SOM decomposition rate as a function of time, in which only one characteristic is required.

Relationship between k and time:

If k is constant, it holds that $dM/dt = -kM$, (1)

where M = OC (g kg^{-1}).

Integrating yields $\int dM = \int -kMdt = -kM\int dt$, such that $dM/M = -kt$, or $\ln M/M_0 = -kt$, yielding

$M_t = M_0\, e^{-kt}$, where (2)

M_0 = Amount of OM at t = 0, (t stated in yr). Therefore, k can be calculated between t and Δt as:

$k = (1/\Delta t)\ \ln(M_t/M_{t+\Delta t})$ (3)

Janssen (1984) using data from different organic materials found that $\ln k = \ln 2.82 - 1.6 \ln t$, that is,

$k = 2.82\ t^{-1.6}$ (4)

Equation 4 cannot be solved for t = 0. So, a 'fixed starting time' had to be found for each organic material.

Equation (4) becomes $k = 2.82(a+t)^{-1.6}$, where (5)

a = age (apparent initial age).

Substituting back into equation 1 yields:

$dM/dt = -kM = -2.82(a+t)^{-1.6}\ M$. After integration: (6)

$\ln M = -2.82/-0.6\ (a+t)^{-0.6} + C$. (7)

If t = 0 (at initiation of the process), then $M = M_0$ = amount of added OM. The integration constant,

$C = \ln M_0 - 4.7\ a^{-0.6}$, thus (8)

$M_t = M_0\ \exp\{4.7[(a+t)^{-0.6} - a^{-0.6}]\}$ (9)

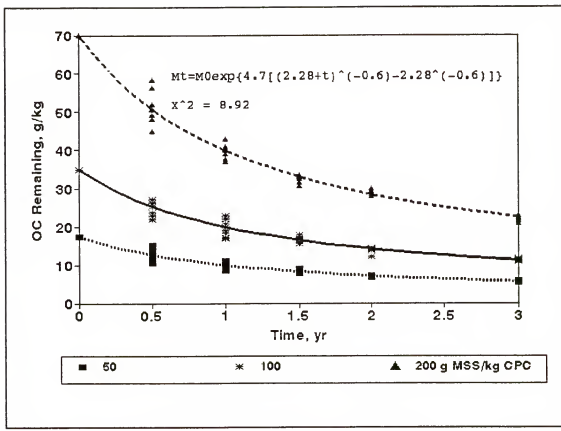


Figure 3-1. Changes in Organic Carbon in a Three Year Glasshouse Experiment, Growing Snap Bean on Sewage Sludge-Amended Phosphatic Clay, 1986-1988.

$h = M_t/M_0$ = humification coefficient, where t = 1.

If any M_t is known, the value of a can be calculated, using equation 8. In practice, knowledge of h, i.e., the humification coefficient, is needed.

Evaluating equation 9 and using the OC value measured at the end of the first year (57% of initial OC), it was found that a = 2.28.

The OC content of the soil (Fig. 3-1) decreased with time from the beginning of the experiment (i.e., time from MSS application). The decomposition rate increased with increasing rate of MSS application. This finding is attributed to an increased energy source for the microorganisms, thereby increasing their decomposition potential. Janssen's SOM decomposition model (1984) accurately predicted the rate of decomposition of MSS in CPC ($\chi^2 = 8.92$).

Nutrient and Heavy Metal Effects. Soil (Kjeldahl) N showed a linear response to MSS rate (Table 3-2) as a consequence of the high N concentration of the MSS when compared with that found in the untreated CPC. Also, M-3 P increased linearly when sludge was applied (Table 3-2). Both M-3 K and Ca (Table 3-2) showed a quadratic response to MSS rate. Whereas the rate of increase of K was a dramatic one, that of Ca was much less so; these responses reflect the low K content in the CPC, and the high content of Ca, compared to MSS. Both Mg and Fe responded linearly to the rate of MSS

(Table 3-2). M-3-extractable nutrients were sensitive to MSS nutritional contributions.

The MSS application also produced an enrichment of micronutrients in the soil (Table 3-2). M-3 Mn, found in low concentration in CPC, showed a quadratic response to MSS rate of application. M-3 Cu and Zn increased linearly with MSS rate.

M-3 Pb and Ni (Table 3-2) showed a quadratic response to the rate of MSS; Pb maximum increase occurred at 130 g MSS kg^{-1} CPC, whereas the maximum increase for Ni occurred at 160 g MSS kg^{-1} CPC. M-3 Cd and Cr responded linearly to the rate of MSS. The small increase of heavy metal content found in these amended soils is due to the application of a MSS low in these metals. In addition, CPC, which contains some metals itself, has a near alkaline pH that may have reduced metal extraction.

Effect of Sludge Application on Plant Growth and Yield

The application of MSS affected all measured growth parameters with the exception of emergence, averaging 74 % ± 0.7% (standard error of the mean), and stem width at blooming (3.59 ± 0.03 mm). Wong et al. (1981) found a depression of seed germination, and speculated that depression was due to gaseous substances contained in the sludge. They demonstrated that the seed germination depression was not caused by Hg, Cu, Zn, Pb, Cd, and Ni, which were found in mostly unavailable forms. They

Table 3-2. Response of Chemical Concentrations of Phosphatic Clay to Sludge Rates at the End of Three Seasons of Snap Bean Production in a Glasshouse Experiment, 1986-1987.

Elem.†	Intercept	Linear	Quadratic	r^2
		g kg^{-1}		
N	0.945±0.248‡	0.023±0.002	NS	0.79
P	0.560±0.043	0.005±4E-4	NS	0.85
K	0.087±0.006	0.0044±1E-4	-3.8E-6±6.6E-7	0.99
Ca	5.56±0.048	0.022±0.0012	-3.7E-5±5.7E-6	0.99
Mg	2.27±0.070	0.023±6.1E-4	NS	0.98
		mg kg^{-1}		
Fe	363±51.6	3.66±0.45	NS	0.69
Mn	9.13±0.17	0.068±0.0044	-8.8E-5±2E-5	0.98
Zn	4.14±0.84	0.251±0.007	NS	0.98
Cu	3.24±0.33	0.078±0.003	NS	0.96
Pb	0.345±0.100	7.3E-4±2.5E-4	-2.8E-6±1.2E-6	0.26
Cd	0.129±0.006	1.9E-4±5.1E-5	NS	0.31
Cr	0.084±0.009	2.0E-4±7.6E-5	NS	0.19
Ni	0.220±0.076	0.0058±6.6E-4	NS	0.55

† Variable of interest. Kjeldahl N; all other nutrients extracted using Mehlich 3.
‡ Estimate ± standard error of estimate. Estimates significant at P = 0.05.
§ Not significant at P = 0.05.

suggested that root elongation is a better parameter than seedling emergence to determine toxic effects on seedlings. Given the characteristics of the CPC, it was impossible to record root elongation. Wollan et al. (1978) found that germination was retarded when fresh sewage sludge was applied, and also speculated that volatile compounds were responsible for this depression. The present experiment did not show retardation of emergence possibly due to the application of dry sludge.

All other measured growth parameters increased in response to MSS rate of application. Biomass yield at blooming responded linearly to this factor (Table 3-3), attaining a maximum (DW) of 3 g per plant. Plant height at blooming showed a quadratic response to MSS rate, with a maximum of 45 cm, at 110 g MSS kg^{-1} CPC.

The number of days to reach maturity increased with an increase in MSS rate, from 50 to 70 d, in a quadratic fashion (Table 3-3). The growing season had an effect on the duration to achieve maturity in the direction Fall '86 > Spring '87 > Spring '86. The fastest rate of decomposition of sludge occurs during the first year after application (Sabey and Hart, 1975), which was the case in this experiment (Fig. 3-1). It was expected that the days to maturity would follow the trend Spring '86 > Fall '86 > Spring '87. Since the effect was higher for the Fall '86, it is suggested that day length and temperature played roles in snap bean development in this glasshouse experiment.

Biomass yield at harvest showed a quadratic response to MSS rate (Table 3-3), with a maximum yield of 8.8 g per plant, at 178 g MSS kg^{-1} CPC. Pod yield (DW) also had a quadratic response to MSS rate (Fig. 3-2), reaching a maximum of 6.4 g pods $plant^{-1}$, at 132 g MSS kg^{-1} CPC. These results are high when compared to the production on native soils, a consequence of the higher nutrient content exhibited by CPC, further enhanced by the addition of MSS.

Economic Growth Rate was not affected by MSS rate, and maintained a level of 0.1 g pods $plant^{-1}$ d^{-1}. Therefore, EGR did not affect the decision to use MSS. Both HI and BGR showed a quadratic response to MSS rate. Harvest Index decreased to a minimum of 0.5 g pods g^{-1} biomass, at 140 g MSS kg^{-1} CPC (Table 3-3), showing that MSS application reduced HI. Biomass Growth Rate increased to a maximum of 0.1 g biomass $plant^{-1}$ d^{-1} at 100 g MSS kg^{-1} CPC. The apparent contradiction between BGR and HI was resolved with the help of pod yield (maximum 132 g MSS kg^{-1} CPC), in close agreement with maximum BGR. Cost of application of MSS should be offset by the increase in revenue due to yield increase.

Effect of Sludge Application on Plant Nutrition

Nitrogen concentration at early blooming was insufficient in all three seasons, when no MSS was applied (Tables 3-4 and 3-5), although no visual deficiency symptoms were detected. This nutrient was strongly related to MSS

Table 3-3. Response of Growth Parameters of Snap Bean Grown on Phosphatic Clay from IMC to Sludge Rates During Three Seasons in a Glasshouse Experiment, 1986-1987.

Parameter	Intercept	Linear	Quadratic	r^2	CV %
EMERG[†], %	34.3±2.6[‡]	0.57±0.07	NS[§]	0.44	9
FMASS, g plt^{-1}	1.14±0.15	0.009±0.001	NS	0.33	39
MDAP, d	48.7±0.9	0.196±0.022	-4.2E-4±1E-4	0.78	2
PLTHT, cm	39.0±0.74	0.097±0.019	-4.2E-4±8.6E-5	0.22	4
MMASS, g plt^{-1}	2.19±0.28	0.082±0.007	-2.6E-4±3.3E-5	0.73	13
HI, g plt^{-1} d^{-1}	2.15±0.17	-0.023±0.004	8.1E-5±2.04E-5	0.31	27
BGR, g plt^{-1} d^{-1}	0.044±5.1E-3	0.001±0.0001	-4.6E-6±6E-7	0.59	13
EGR, g plt^{-1} d^{-1}	0.064±6.5E-3	6.9E-4±1.7E-4	-3E-6±7.7E-7	0.16	26

[†] EMERG = % Emergence; FMASS = Biomass yield at blooming; MDAP = Days to maturity; PLTHT = Plant height; MMASS = Biomass yield at harvest; HI = Harvest Index; BGR = Biomass Growth Rate; EGR = Economic Growth Rate.
[‡] Estimate ± standard error of estimate. Estimates are significant at P = 0.05.
[§] Not significant at P = 0.05.

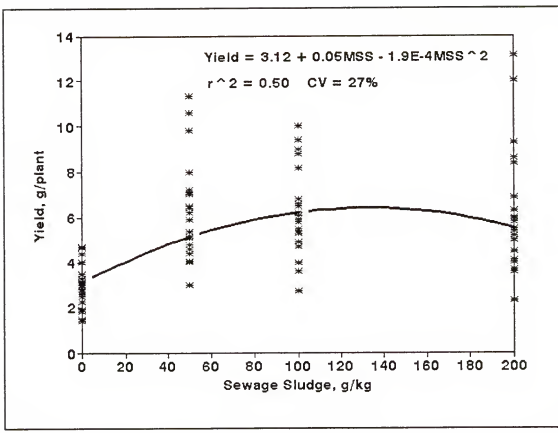


Figure 3-2. Effect of Municipal Sewage Sludge on Pod Yield (DM) of Snap Bean Grown on Phosphatic Clay from IMC in a Three-Season Glasshouse Study.

Table 3-4. Response of Foliar Nutrient Concentrations of Snap Bean Grown on Phosphatic Clay from IMC to Sludge Rates During a Three Season-Glasshouse Experiment, 1986-1987.

	Intercept	Linear	Quadratic	r^2	CV %
		All Seasons			
N[†]	26.4±0.43[‡]	0.16±0.01	-4.9E-4±5E-5	0.83	4
Ca	19.7±0.94	0.13±0.02	-3.7E-4±1.1E-4	0.47	18
Mn[#]	19.7±0.69	NS[§]	5.4E-4±3.3E-5	0.73	20
		Spring 86			
P	3.46±0.14	-0.016±0.004	5.2E-5±1.6E-5	0.56	14
K	9.65±1.01	0.023±0.009	NS	0.18	33
Mg	8.97±0.28	NS	NS	NA[¶]	18
Cu[#]	4.27±2.33	NS	6.2E-4±1.1E-4	0.50	83
		Fall 86			
P	3.31±0.08	-0.004±6.5E-4	NS	0.52	9
K	19.0±0.76	NS	NS	NA	10
Mg	6.85±0.29	0.043±0.007	-1.5E-4±3.4E-5	0.65	10
Cu[#]	6.70±1.16	NS	3.3E-4±5.6E-5	0.54	46
		Spring 87			
P	3.39±0.08	NS	-1.2E-5±3.9E-6	0.23	11
K	27.0±0.48	-0.009±0.004	NS	0.14	5
Mg	5.38±0.18	0.068±0.005	-2.3E-4±2.2E-5	0.92	5
Cu[#]	9.59±0.54	NS	NS	NA	32

[†] Nutrient of interest. Estimates significant at P = 0.05. Units are g kg^{-1}, except where indicated by [#], mg kg^{-1}.
[‡] Estimate ± standard error of estimate.
[§] Not significant at P = 0.05.
[¶] Not applicable.

Table 3-5. Nutrient Sufficiency Levels for Most Recently Matured Leaves at First Blooming of Snap Bean.

Nutrient	Sufficiency Range Min.	Max.	Nutrient	Sufficiency Range Min.	Max.
	—— g kg^{-1} ——			—— mg kg^{-1} —	
N	30	40	Fe	25	200
P	2.5	4.5	Mn	20	100
K	20	30	Zn	20	40
Ca	8	15	Cu	5	10
Mg	2.6	4.5			

Extracted from Hochmuth et al., 1991.

Table 3-6. Average Foliar Concentrations of N, Ca, Mn, and Zn, by Season, of Snap Bean Grown on Municipal Sewage Sludge-Amended Phosphatic Clay, 1986-1987.

Season	N	Ca	Mn	Zn
	g kg^{-1}		mg kg^{-1}	
Spring 86	33.0±0.31[†]	30.4±1.17	28.4±2.02	23.0±1.05
Fall 86	34.1±0.14	26.6±0.96	26.8±1.7	27.6±0.85
Spring 87	34.7±1.06	22.7±0.96	25.0±0.6	32.0±0.95
Contrasts[§]				
SP86 vs. FL86	**	**	NS[‡]	**
FL86 vs. SP87	NS	**	NS	**
CV, %	4	18	20	23

[†] Mean ± Standard error of mean.
** Significant at P = 0.01.
[§] FL86 = Fall 86; SP86 = Spring 86; SP87 = Spring 87.
[‡] Not Significant at P = 0.05.

application (r^2=0.83), and showed a quadratic response to MSS rate, reaching a maximum at 163 g MSS kg^{-1} CPC, close to the rate for maximum pod yield. Nitrogen foliar concentration increased from Spring '86 to Fall '86, but not from Fall '86 to Spring '87 (Table 3-6). That tendency suggests a release of N as MSS decomposed.

Leaf tissue Mn was also insufficient when no MSS was applied (Tables 3-4 and 3-5) in all seasons. No visual deficiency symptoms were detected either. Foliar Mn was strongly related to MSS application (r^2=0.73), with an exponential response to MSS rate. Mn foliar concentration tended to decrease from Spring '86 to Spring '87, although Fall '86 (Table 3-6) showed an intermediate value, no different from either Spring seasons.

Leaf tissue P, Mg, and Cu were affected by an interaction of MSS rate and season, with moderate to high coefficients of determination (Table 3-4). Foliar P concentration tended to decrease with MSS rate increase, always within a sufficient range (Table 3-5). That decrease was attributed to an increase in yield, and a dilution effect, since the available P volume was about constant throughout the growing period. Magnesium, with an average value of 9.0 g kg^{-1} during the first season, showed a quadratic increase during both Fall '86 and Spring '87 seasons (Table 3-4), and was always above the adequate range for snap bean at this growth stage (Table 3-5). Copper

foliar concentration during Spring '86 was insufficient when no MSS was applied (Tables 3-4 and 3-5) but increased during both seasons of '86, responding to MSS rate of application, and remained constant (9.6 mg kg^{-1}) throughout the last season. That trend of Cu suggests that MSS decomposition may have rendered Cu more available to plants.

Foliar concentrations of Ca and K, showed weak relationships to MSS rate (Table 3-4), whereas Zn and Fe foliar concentrations did not depend on MSS rate. Calcium foliar concentration showed a quadratic response to MSS rate during the three growing seasons. Calcium concentration decreased steadily with time after application (Table 3-6), but always remained above the sufficiency range (Table 3-5). Potassium foliar concentration was insufficient during the first two growing seasons (Tables 3-4 and 3-5) and increased with time after application. It is suggested that MSS decomposition increased K release. Foliar Zn concentration was not affected by MSS rate, but OM activity may have increased its availability to plants, and its concentration was always within the sufficiency range (Table 3-5). Zn foliar concentration increased with season after application (Table 3-6). This nutrient might have been in competition with Ca. Iron was the only nutrient whose foliar concentration was not affected by either season or rate of MSS application, maintaining an average of 91.7 mg kg^{-1}, well within the sufficiency range (Table 3-5).

The non-essential heavy metals Pb, Cd, Cr, and Ni appeared unaffected by either MSS rate or season. Their concentrations in leaf tissue were < 0.1 mg kg^{-1}, which caused confounding with background interference. No visual symptoms of toxicity were detected from any of these metals. This finding suggests that MSS application at high rates in the field will not pose any immediate danger to vegetables.

Conclusions

The anaerobically digested sewage sludge from the city of Tampa served as a soil amendment with no detrimental effects to snap bean.

Organic carbon content of the soil increased as a result of applying MSS; the effect persisted over three years of study. The rate of OC decomposition increased with increasing rate of MSS application.

With the exception of N, CPC contains high amounts of nutrients, compared to surrounding soils. Addition of MSS further enhanced the difference. However, undesirable heavy metals concentrations also increased slightly.

Yields and growth were improved by MSS addition. Foliar concentrations of nutrients increased with MSS rate, suggesting a higher availability of nutrients. By contrast, heavy metal foliar concentrations were not affected, although they had been found to increase in the soil. The latter phenomenon suggests that heavy metals were sorbed to CPC, and that uptake per plant increased, but so did biomass

yield, leaving concentration unaltered. The accumulation in the soil in this study implies that problems might arise in the future, if MSS is applied continuously.

In summary, the results of the present study confirmed the hypothesis that CPC is a source of nutrients for snap bean. Furthermore, it was proven that MSS can enhance snap bean growth on CPC, even at high rates (200 g MSS kg^{-1}) with no deleterious effects.

CHAPTER 4
SWEET CORN PRODUCTION ON SLUDGE-AMENDED PHOSPHATIC CLAYS

Introduction

The phosphatic clay at the Agrico site, similar to CPC from IMC, contained low levels of organic matter, (Table 2-1), when compared with surrounding unmined soils. While buildup of organic material has been shown to ameliorate some adverse soil physical characteristics (Felton and Ali, 1992; Hinesly et al., 1984; Joost et al., 1987), the hot humid climate of Florida promotes rapid breakdown of organic materials (Atlas and Bartha, 1981).

The ever increasing prices of commercial fertilizers, and the need for disposing of municipal wastes have increased the interest of using MSS for spreading on agricultural land in the United States. This interest dates back to the late 1920's, when dried activated sludge from Milwaukee, WI, became commercially available (Anderson, 1959). With the present public awareness for environmental issues, the application of MSS to croplands is becoming a viable disposal alternative. Land spreading is one of the most economical methods of MSS disposal. It also can fulfill the nutrient requirements of crops grown on amended soils (Hinesly and Sosewitz, 1969; Kelling et al., 1977).

The economics of MSS land spreading has to consider the proximity of the treatment facility to the cropland. Thus, this option is more attractive to farmers near municipalities.

Some inherent undesirable side effects limit the use of MSS as a source of plant nutrients, including soil accumulation of heavy metals, groundwater pollution, soluble salts, and pathogens (U.S. EPA, 1993). The MSS application to cropland is often governed by the N content of the sludge applied, and the N required by the particular crop. The plant available N content (inorganic N plus a percentage of the organic N) of MSS is used as the basis for calculating annual application rates, which should provide between 1.5 to 2 times the crop's N fertilizer requirement (U.S. EPA, 1977).

The amount of available N is a function of several processes, including ammonia volatilization, nitrate leaching, and organic carbon mineralization. Sommers et al. (1981) found that less ammonia volatilized when sludge was incorporated; ammonium was rapidly immobilized, and the amount of mineralizable N was proportional to organic N content.

Kiemnec et al. (1990) applied MSS of low metal concentrations from two different cities to sweet corn and found them to be satisfactory sources of N. They applied 13 Mg lime ha^{-1} to a Willamette silt loam (fine-silty, mixed,

mesic Pachic Ultic Argixeroll) and found higher yields in limed plots, which also showed lower Cd, Zn, and Mn concentrations in leaf tissue, than unlimed plots. Lime rate increased pH from 5.1 to 5.5 and 5.7. The authors concluded that MSS with low metal concentrations can be used in long-term annual applications as an N source for sweet corn production on a moderately acidic soil. Although Kiemnec et al. (1990) found a positive yield response to pH increase, they suggested that increasing pH above 6.5 might not be economical for sweet corn production, based on the amount of lime used in their study.

Recent economic studies, also a part of the MLAR/DP, indicated that there is a possible market for sweet corn in the central Florida area (Rahmani et al., 1990). Thus, sweet corn was chosen for this experiment.

This study was conducted to determine the effects of MSS amendment on the characteristics of reclaimed CPC under field conditions, and on the yield of sweet corn grown on CPC. The second objective was to apply the decomposition model tested in the glasshouse (Chapter 3) to this field study. The third objective was to determine which sweet corn cultivars would perform best in this environment.

Materials and Methods

A sweet corn experiment was conducted at the Agrico site of the MLAR/DP on reclaimed CPC that was deposited on

unmined surface soil. The depth of the CPC after consolidation was about 1 m. The experiment was carried out for five seasons: Fall '86, Spring '87, Fall '87, Spring '88, and Spring '89.

A strip-plot design allowed the use of mechanized planting and MSS applications. Four replications of four levels of MSS in a complete factorial arrangement with four sweet corn cultivars (Bonanza, Merit, Silver Queen, and Staysweet) were planted in this experiment, except for the last season, when only cv. Merit and Staysweet were planted. Each plot contained six rows of sweet corn on 0.9-m centers. Each corn row was 12.2 m long, with 20 cm between plants.

Anaerobically digested MSS cake (14% solids) from the City of Tampa was donated to the MLAR/DP and spread by the Land Restoration Corp. on 8 October 1986, 16 September 1987, and 5 March 1989. The MSS was incorporated into the soil to a depth of 10 cm using a rototiller.

The MSS rates were increased with time due to lack of response. However, rates were selected without MSS disposal in mind. The first application was made at rates of 0, 4, 8, and 16 Mg MSS ha^{-1}; the second application was at rates of 0, 8, 16, and 32 Mg MSS ha^{-1}, and the last application at rates of 0, 14, 28, and 56 Mg MSS ha^{-1}.

Samples of the MSS were taken before each application and analyzed for moisture content, Kjeldahl N, and P, K, Ca, Mg, Zn, Mn, Cu, Cd, and Pb by a dry ashing method.

An initial CPC sampling was taken prior to the experiment (Table 2-2). Samples were taken prior to planting each season. These samples were analyzed by Mehlich-3 extraction for P, K, Ca, Mg, Zn, Mn, Cu, Cd, and Pb. pH was determined using 2:1 water:clay mixture. Organic carbon was determined by the Walkley-Black procedure. The decomposition model used in Chapter 3 was also used to fit OC decay in this experiment. However, each addition of MSS and stover was accounted for when modelling this experiment.

Fertilizer applications were based on the crop nutrient requirement concept and adjusted to account for estimated N release from the MSS. Residual N fixed by alfalfa (Medicago sativa L.) prior to the initiation of this experiment was accounted for by soil analysis. Ammonium nitrate was added to supply 34 kg N ha^{-1} in Spring '87 and Fall '87, and 65 kg N ha^{-1} in Spring '88 and Spring '89. No other fertilizer applications were made, based upon soil-test results.

Sweet corn was planted on 13 October 1986, 5 March and 24 September 1987, 2 March 1988, and 8 March 1989. Tissue from the most recently matured leaf was collected at tassel (approximately the R1 growth stage), and oven-dried at 70 C to constant weight. Each entire sample was then ground to pass a 1-mm screen, using a stainless steel Wiley mill. Total Kjeldahl N (TKN) was determined on the samples. One-gram samples were weighed and dry-ashed, and digested for

chemical analysis (Hanlon and DeVore, 1989). Analyses included P, K, Ca, Mg, Zn, Mn, and Cu using the ICAP.

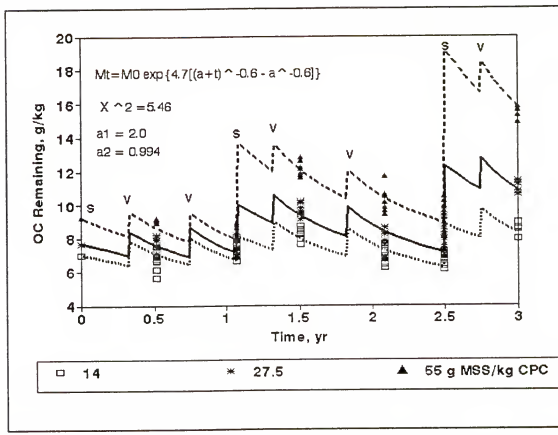
At maturity, corn ears were hand-picked, from the innermost two rows. Ear length, width, marketable weight and number, plant height and plant numbers were measured from the center two rows of each plot.

All statistical analyses were performed at $P = 0.05$ level of significance using SAS procedures (SAS, 1988). The data were subjected to analysis of variance (ANOVA) with single degree of freedom contrasts and, when appropriate, regression analysis. The model from OC change was subjected to χ^2 goodness-of-fit analysis.

Results and Discussion

Effect on Soil Composition

Change in soil organic carbon. Janssen's model for soil OC decomposition used in Chapter 3 was modified to account for the addition of stover at rates between 1.7 and 1.8 g kg^{-1} CPC during each season, and for the addition of MSS at three different times (Fig. 4-1). The **a** value of 2.28 found in Chapter 3 for MSS was used in the present experiment, and an additional **a** value of 1.21 was computed for stover. There was good agreement between the remaining OC predicted by the model and that found in the soil ($\chi^2 = 5.46$). In general, the model tended to underestimate the rate of decomposition.



a_1 = Apparent initial age for municipal sewage sludge.
a_2 = Apparent initial age for corn stover.

S = Application of municipal sewage sludge.
V = Application of corn stover.

Figure 4-1. Changes in Organic Carbon in a Five-Season Experiment, Growing Sweet Corn on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico Site, 1986-1989.

An iterative goodness-of-fit analysis run on the model proved that the **a** value found for MSS in Chapter 3, and the calculated **a** value for stover did not apply under field conditions. New values for a best fit were generated in this manner, resulting in $a_1 = 2.0$ for MSS, and $a_2 = 0.994$ for stover, similar to **a** = 0.99 for green matter. Unlike **a** = 2.28 (Chapter 3), which was similar to the value found by Janssen for litter, the new a_1 had no comparison with any of Janssen's apparent initial age values. The significance of a lower **a** for MSS is that under field conditions the rate of decomposition was higher. A sensitivity analysis showed that the model was more sensitive to a change in a_2 than to a_1 by an order of magnitude. The last finding was a result of differences between the composition of the stover and MSS. The stover contained highly decomposable materials, compared to the previously digested MSS.

The difference between the OC remaining in the soil between the highest MSS rate and no MSS addition suggests that the rate of decomposition of OC from MSS is lower than that from the stover, in agreement with the finding of Moorhead et al. (1987). As a consequence, application of MSS increased SOM accumulation. Whereas MSS had undergone a digestion process, stover had not. Therefore, stover contained more decomposable materials than did MSS. Thus, stover decomposed more rapidly, and that showed in a lower a_2. The inorganic N added at the time of stover

incorporation aided in the decomposition of both stover and MSS, as opposed to the glasshouse experiment, where no N was added.

At the end of the study, the total addition to the soil at the highest MSS rate was 31.5 Mg OC ha^{-1}, comprising both MSS and returned stover. The soil OC retention increased from 9%, without MSS added, to 43%, at the highest MSS rate. Liang and McKenzie (1992) added manure and corn stover to a Chicot sandy clay loam (fine-loamy, mixed, frigid Typic Hapludalf) in Canada, and obtained a retention of 23.4% over 6 yr. Results of OC retention in the present study, under conditions of higher temperature to promote OC decomposition rate, are lower than those of Liang and McKenzie's study (1992). A higher decomposition rate was expected from the present study. It is suggested that restricted pore air-flow in the CPC slowed OC decomposition. Furthermore, newly reclaimed soils lack the microbial population that promotes SOM breakdown. By contrast, the warm, humid climate of the region may have promoted SOM decomposition.

Change in soil nutrient concentrations. Because initial M-3 extractable values were large, addition of MSS was not expected to affect M-3 extractable P, K, Ca, Mg, Zn, Mn, Cu, or Fe. Analysis of variance using a split-plot-in-time model confirmed that MSS treatments did not increase M-3 extractable nutrients ($P>0.05$, Table 4-1).

Table 4-1. Results of Mehlich-3 Extraction on Municipal Sewage Sludge-Amended Phosphatic Clay on a Five-Season Sweet Corn Experiment at Agrico, 1986-1989.

Element	Concentration	Critical value[†]
	mg dm^{-3}	
P	551±19[‡]	30
K	400±19	N/A[§]
Ca	5 491±38	47
Mg	2 270±19	61
Fe	249±6.3	N/A
Mn	3.2±0.2	4
Zn	8.1±1.7	1
Cu	4.3±0.3	0.5

[†] North Carolina State Interpretation.
[‡] Mean ± standard error of mean. Number of observations = 32.
[§] Not applicable.

Sweet Corn Yield Measurements

Overall sweet corn production was equivalent to the Florida average of 5.6 Mg ha^{-1} (Fig. 4-2). While MSS rates had no effect on yield, season and cultivar, and their interaction were significant. There was a general crop failure during the Fall '86 season due to severe water stress. No irrigation was available during that season. Irrigation pump installation was not completed until the Spring '87 season.

Merit produced higher yields than all other cultivars, followed by Staysweet, Bonanza, and lastly, Silver Queen, throughout the experiment. Only Merit produced any marketable yield during the last season, and it was extremely low.

The production of yields equivalent to the Florida average was the result of several factors. The dominant reason for low yields found in the study was an inability to control loss of corn ears to the local wildlife. Loss of mature ears due to bird and/or raccoon activity varied from 50 to 100%. Comparison of the Fall '87 yield of Staysweet (5.7 Mg ha^{-1}) with that of the number of ears, 70 110 ears ha^{-1} (96% stand), indicated an estimated potential yield of 13.2 Mg ha^{-1}. Thus, about 60% of the crop was lost due to predation, even after an electric fence was placed around the entire 1.5-ha study site. This excessive loss was exaggerated somewhat by the nature of small-plot research.

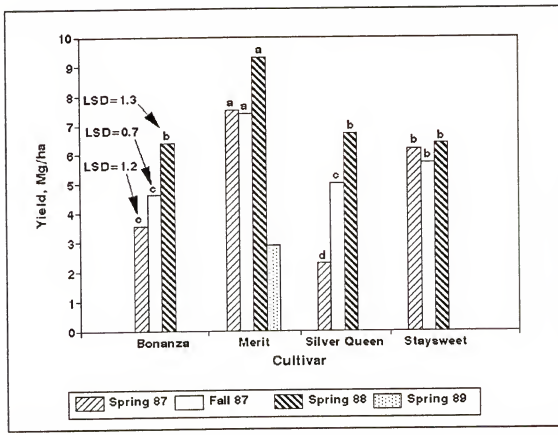


Figure 4-2. Yield of Sweet Corn Cultivars, by Season, on a Five-Season Field Study on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico, 1986-1989. LSD Comparison is Valid Within Season, Over Cultivars. Only "Merit" was Harvested in Spring 1989, and no Comparison is Applicable.

Secondly, sweet corn was planted on leveled CPC, exposing the corn to excessive moisture. The importance of surface microrelief has resulted in the development of macrobeds for subsequent crops grown at the MLAR/DP.

Lastly, planting must be done when seasonal precipitation permitted 1 to 2 weeks of drying so that an appropriate seed bed could be prepared in the CPC. Delays of 1 month were not uncommon between the desired planting date and the actual planting date. Once planted, plant stands would often be < 60% of the desired level, necessitating replanting the field.

Sweet Corn Tissue Analyses

Statistical findings. The main effect of season was found significant ($P < 0.05$) for Mn concentrations only, while the main effect of cultivar was found significant ($P < 0.05$) for Zn. The interaction of season and cultivar was found to affect concentrations of Fe, Zn, and Cu. There was no effect of MSS on nutrient tissue concentrations.

Agronomic findings. A comparison of the main effect and interaction means discussed above showed no practical difference among seasons (Table 4-2), and indicated that tissue concentrations of P and K were above reported critical values for sweet corn (Hochmuth et al., 1991). Manganese, however, was considered "low," the mean seasonal concentration was found to be just below the reported sufficiency range. All other nutrients were well above the

Table 4-2. Leaf Tissue, Early Tasseling Stage, Nutrient Concentration of Sweet Corn Grown on Municipal Sewage Sludge-Amended Phosphatic Clay at Agrico, 1987-1989.

	Season				
Nutrient	SP87†	FL87	SP88	SP89	Adequate‡
	g kg^{-1}				
N	20	26	24	36	25-40
P	1.9	2.6	2.3	2.9	2-4
K	18	18	19	19	20-35
Ca	3.6	4.0	4.2	5.3	3-6
Mg	2.9	3.1	3.4	3.4	1.5-4
	mg kg^{-1}				
Zn	46	55	56	37	20-40
Mn	17	19	18	11	30-100
Cu	9	6	6	11	4-10
Fe	112	120	123	183	30-100
B	60	80	18	22	10-20

† SP87 = Spring 1987; FL87 = Fall 1987; SP88 = Spring 1988; SP89 = Spring 1989.
‡ From Hochmuth et al., 1991.

critical values or in the upper portion of the sufficiency range. These data indicated that nutrition was not limiting sweet corn production, except possibly for Mn. Mn has been subsequently found to be low for other commodities grown on phosphatic clays.

Conclusions

Addition of MSS increased the levels of OC in the soil. The OC decomposition model fit the data for MSS and stover added to CPC. The rate of decomposition was higher under field conditions than that found under the glasshouse (Chapter 3). Changes in temperature and moisture in the field appear to have enhanced the decomposition of the materials. The composition of the material influenced the model, which was more sensitive to fresh material than to the more stable MSS.

Addition of both MSS and stover had a weak relationship (r^2=0.1) with N soil concentration. A larger effect was expected as a result of MSS addition. It is assumed that excessive moisture conditions occasionally found in the field induced denitrification. The effect of MSS on M-3 extractable nutrients was also weak (r^2<0.2 for all nutrients). A higher rate of MSS than that used in the present study would be necessary to induce a significant change in extractable nutrients.

Sweet corn cv. Merit produced higher yields than all other cultivars, showing its adaptability to the

environmental conditions of the experiment. Other cultivars that human consumers prefer compared to cv. Merit performed poorly. The yields found in this experiment were greatly affected by the wildlife of the area. To produce corn or any other palatable vegetable in the area, losses due to animals should be controlled.

The results of this study confirmed that CPC provided adequate amounts of most nutrients, except N, and possibly Mn. Low levels of Mn in both CPC and MSS, when compared with other nutrients appear to have played a role on foliar low levels of Mn. No harmful effects of MSS addition were found.

Nutrition and fertility were not the controlling factors for sweet corn production on CPC. Phosphatic clay can serve as a receptor for disposal of MSS, alleviating a municipal environmental problem and improving the nutritive value of CPC.

CHAPTER 5
WATER MANAGEMENT FOR SEEDBED PREPARATION AND SEED COVER FOR VEGETABLE STAND ESTABLISHMENT ON PHOSPHATIC CLAYS

Introduction

Soil management of reclaimed CPC is critical in the restoration process of these materials. A major concern with CPC is the preparation of adequate seedbeds for crop establishment. Either excessive or too little water content makes tillage extremely difficult. Inadequate soil moisture can prevent germination, and soil crusting can reduce seedling emergence. However, the range of soil structure and moisture characteristics adequate for satisfactory phosphatic clay seedbeds is not known. Quantitative information is needed to characterize the response of these materials to different irrigation and tillage practices.

Alteration of Seed Microenvironment

Good soil-seed contact is crucial for seed germination and plant emergence. Current vegetable production techniques include strategies for seed bed preparation on unmined sandy soils. However, mining operations have resulted in the formation of phosphatic clays, whose properties are dramatically different from the unmined mineral soils in central Florida. After reclamation, these

clays must be further altered if vegetable production is to be competitive with other growing areas within Florida.

Gross alteration of the physical characteristics (e.g., addition of sand to modify stickiness) of these soils requires SCR of 4:1 to improve feasibility of tillage and bed-forming operations (Million et al., 1987). The maximum SCR that can be pumped was found to be 2:1; therefore, additional sand must be incorporated after consolidation. Since sand and CPC are found in roughly equal portions within the ore, not enough sand is available from mining. Thus, sand from other sources must be shipped into the area, increasing the operational costs. However, modification of the CPC in the vicinity of the seed may be feasible.

Expansion of the swelling clayey soil begins immediately upon wetting, with a consequent decline in infiltration rates. As the soil approaches saturation, infiltration ceases, causing poor internal drainage contributing to soil-aeration problems, and a consequent detrimental effect on plant growth. This condition of saturation occurs most frequently in the early spring growing season.

Dexter et al. (1984) showed that intermittent wetting and drying cycles of the surface soil can result in the breakdown of compacted clods and of rough surfaces, in a self-mulching phenomenon termed "tilth mellowing" or simply "mellowing."

The alternating expansion and contraction of CPC during wetting and drying contributes a self-mulching characteristic. In swelling clayey soils, a vigorous disruption action is associated with swelling. As water is absorbed, the volume increases, cohesion is diminished, and any unconfined mass of the soil exhibits warping, cracking, exfoliation, and various degrees of disruption (Smith, 1959). Low and Margheim (1979) found that the swelling pressure is due primarily to a reduction in the potential energy of the interlayer water as a result of its interaction with adjacent layer surfaces. Aggregation and porosity of surface clayey soils may be enhanced as a result of the mellowing process.

The configuration of the soil surface is an important characteristic in the evaluation of tillage methods, seedbed preparation and other soil management operations (Patterson et al., 1980; Stafford and Ambler, 1988). Surface roughness affects many physical characteristics such as infiltration, solar radiation and reflection, soil temperature, evaporation, erosion, trafficability, and most importantly, soil-seed contact leading to germination.

Soil surface roughness influences important processes occurring at the soil surface, such as runoff, depression storage of water, and evaporation. It also affects processes occurring lower in the profile that affect the growing conditions of plants, such as infiltration and

moisture replenishment. Surface roughness is affected by texture and structure, as well as soil management practices, such as incorporation of organic matter, tillage methods, and tillage implement selection.

The quantitative description of soil surface roughness enables the comparison of different tillage practices. It may aid in the selection of tillage practices in terms of efficiency, cost, time consumption, and soil conservation.

Researchers have used several parameters to describe soil surface roughness. Kuipers (1957) was the first to quantify soil surface roughness, using a reliefmeter with 20 pins 10-cm apart to obtain a profile measurement. Burwell et al. (1963), using a similar device, separated variations in elevations due to tillage tool marks and wheel tracks, from those that occur at random, using the term "random roughness." A random roughness index, R, is defined as the standard error among the logarithms of elevation measurements (Burwell et al., 1963; Allmaras et al., 1966). Dexter (1977) calculated an autocorrelation function for surface height measurements taken 0.5-cm apart. He concluded that the autocorrelation function at a lag of zero, or Kuipers roughness parameter, R, still provided the best estimate of surface roughness.

Recently, other surface roughness indices have been proposed (Römkens and Wang, 1986) to include direct elevation measurement with frequency of occurrence of peak

heights or depression depths. Lersch (1988a) applied the methodology of Römkens and Wang (1986) to determine the effects of cultivation, rainfall, and crop canopy development on soil surface roughness. He evaluated several surface roughness parameters, and concluded that a parameter combining a microrelief index, proposed by Römkens and Wang (1986), with the peak frequency showed the highest potential in correctly predicting crop response to surface preparation. Lersch (1988b) found that soil physical properties that affected surface roughness to the greatest degree were bulk density, water content at time of cultivation, and texture.

Numerous researchers have noted that rainfall decreased soil surface roughness (Burwell et al., 1966; Burwell and Larson, 1969; Dexter, 1977). Most have related alteration of the soil surface to raindrop energy impact, causing aggregate breakdown (Burwell and Larson, 1969; Johnson et al., 1979; Römkens and Wang, 1986), or particle translocation on the soil surface (Burwell et al., 1966).

Hirschi et al. (1987) present an account of several of the different reliefmeter designs. All others are a modification or an improvement of one or more of these basic designs. In many of the designs (Kuipers, 1957; Burwell et al., 1963; Allmaras et al., 1967; Curtis and Cole, 1972; Moore and Larson, 1979), surface height was measured from the displacement of pins which were lowered from a reference

level until the pin touched the soil surface. The earlier studies relied on visual observation, and manual digitization. Photographic recording and manual or electronic digitization have been time-saving improvements.

Recent advances in technology (especially computer hardware and software) have enabled the development of computer-controlled devices, with such features as non-contact optical recording and electronic digitization (Harral and Cove, 1982; Van Ouwerkerk et al., 1982). Costs are high for such equipment.

One of the impediments to agricultural production on these fertile clays is that increased tillage is required to prepare suitable vegetable seedbeds. Most vegetables are produced in Florida using a full-bed, polyethylene-mulch cultural system that requires a rather smooth, clod-free soil structure to create the final bed shape. It seems reasonable to expect that overhead irrigation could be used to cause large clod breakdown (so-called mellowing) reducing the required tillage operations. Changes brought about by sequential irrigations could then be measured by related changes in surface roughness.

Once a reasonably acceptable seed bed surface has been achieved, additional tillage operations can be avoided by selecting appropriate planting techniques, such as transplanting or selected seed covering techniques. Seed covers offer three major benefits: a) direct contact with

medium; b) enhanced water availability, and c) amelioration of any potentially adverse condition in the soil. Seed covers offset such negative effects of large clods as the loss of seed between clods to depths from which the plant can not grow successfully, or poor soil/seed covering.

Transplanting offers several advantages over direct seeding, such as: 1) established plants with roots have better success in an adverse environment; 2) results in complete, uniform plant stand; and 3) crop flowers and fruits earlier.

Seed covers have proven successful in commercial farming operations on unmined mineral soils in Florida. Their major advantage over transplants is a much lower cost. Three covers were selected for this experiment: LVM 6/30, plug-mix, and screened CPC.

LVM 6/30 is a material resulting from firing montmorillonite clays at high temperatures to change the crystalline structure. A commercially available type used in this study was GrowSorb, manufactured by Mid-Florida Mining, Inc.

Plug-mix is a mixture of peat, vermiculite and/or perlite, fertilizer, water, and seeds. Hayslip (1973) developed the technique, and found that it reduces soil crusting. Plug-mix also induced a more rapid and uniform seed germination, and more vigorous plants compared to seeding directly in soil. However, under hot and windy

conditions, plug-mix should be watered frequently, to avoid drying and seed exposure.

Given the availability of material, finely screened CPC was used for comparison with proven covers. Since CPC has been shown to hold considerable water compared to sandy soils (Chapter 2), it was hoped that CPC would prove to be a good seed covering.

A field experiment was conducted to explore effects of wetting and drying cycles induced by overhead irrigation on CPC surface roughness. In addition, transplanting was compared to selected seed covers, which were compared among themselves, to reduce the influence of surface roughness on seedling emergence and harvested yield and quality.

Materials and Methods

Field Operations

The study was conducted on a reclaimed settling pond at the Mined Lands Agricultural Research/Demonstration Project at Mulberry, Polk Co., FL, in 1988 and 1989. A split plot experiment was arranged in a factorial design, with surface conditions as main plots, and seed coverings as subplots, with five replications. Main plot size was 36.6 m x 11 m.

Initial bed soil preparation consisted of plowing at 15-cm depth, and a rototiller pass at 10-cm depth, followed by one bed-press pass. Nitrogen fertilizer (NH_4NO_3) was applied during field preparation at a rate of 168 kg N ha^{-1}.

Crops were grown on raised (15 cm) beds 0.76-m wide, 2 m apart, covered with plastic mulch. There were two rows per bed, 46 cm apart, with 28 cm between plants within rows. Seeds were sown through 7-cm diameter holes in the mulch into small depressions. Planting was done by hand. Four nongerminated, dry seeds were planted per hole, and covered with either 30 mL LVM 6/30 or screened CPC, using a porcelain cup. A third treatment consisted of inserting seeds into a 60-mL aliquot of plug-mix, and placing the mix in the hole.

Bell pepper (Capsicum annuum L. cv. Gator Belle) was transplanted on 1 April 1988, and direct-seeded on 5 April 1988 (Spring '88). Cucumber (Cucumis sativus L. cv. Hybrid Dasher II) was direct-seeded on 6 September, and transplanted on 13 September 1988 (Fall '88). During Spring '89 season, the same cultivar of cucumber was direct seeded on 1 March, and transplanted on 10 March.

Immediately after a plot was covered with plastic mulch, a reliefmeter devised and built by E.A. Hanlon and R.A. Jerez was used to measure surface elevations. The measurements were made on the surface after cutting a strip of plastic mulch, perpendicular to the crop rows, on three separate transects spaced 5 cm apart.

Reliefmeter

The complete reliefmeter system consisted of four sections:

a. mechanical system, which consists of an aluminum frame, supporting a vertical backboard.

b. measuring system, consisting of a horizontal board mounted on the aluminum frame, and containing fifty steel pins 50-cm long of 2.3-mm diameter, aligned 1-cm apart.

c. recording system, consisting of a photographic camera, mounted on two arms attached to the vertical backboard at a fixed distance.

d. digitizing system, consisting of a digitizing tablet, using a computer program to record the height of the measuring pins from an enlarged photocopy of the picture taken in the field.

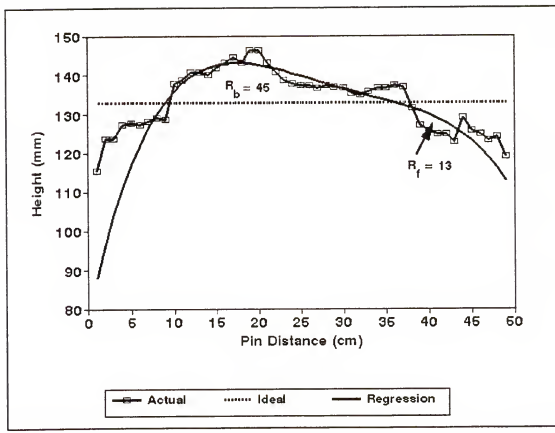
Roughness Index

Pin heights were compared using the following formula:

$$R_f = 100 \times (\log SE),$$

where the standard error of the pin heights (SE) was calculated from a quartic regression that described the bed surface.

This formula is a modification of that proposed by H. Kuipers (1957) to provide a comparison of surface roughness among selected tillage methods. The same logic was used to calculate another index, R_b (Fig. 5-1), based on an average height value of the seedbed, rather than on a value calculated by a regression equation. To calculate R_b, an idealized, flat, leveled surface of the bed was assumed.



R_f = Surface Roughness Coefficient Using Differences Between Actual Pin Height and Quartic Regression.

R_b = Surface Roughness Coefficient Using Differences Between Actual Pin Height and Ideal Surface.

Figure 5-1. Example of Pin Height Measurement, Regression Line Describing the Average Bed Surface, and Horizontal Line Simulating an Ideal Bed Surface in Cucumber Field Study at IMC, 1988.

After the seedbed was formed, all plots received 2-cm irrigation (overhead), and were allowed to air-dry until it was possible to cover the bed with the plastic mulch. At this time, 20 plots were covered, and the remaining uncovered plots received a second irrigation. After a second drying cycle, an additional 20 plots were covered. The remaining 20 plots received a third irrigation and drying cycle before being covered.

The surface configuration obtained after the first irrigation was considered "coarse," after the second, "medium," and after the third, "fine," following the classification adopted by Johnson et al. (1979). Soil surface roughness measurements were repeated at harvest to determine if additional changes were caused by conditions under the plastic mulch.

Data handling. An instant color picture was taken of the pins from each of the three transects using a Polaroid 600 camera. An enlarged photocopy of each picture was digitized and used to obtain the actual pin heights, in millimeters, using a digitizing tablet and a HP-9816 computer running a program written in BASIC for this purpose. The data from each subplot and transect were electronically encoded and then statistically analyzed.

Statistical analyses. The pin-height data were subjected to a backward stepwise regression procedure, using the Statistical Analysis System (SAS, 1988) REG procedure up to

a quartic model, to obtain the best fit equation. This equation was then used for comparison with the actual height values, as obtained in the field, to calculate the R_f and R_b.

Surface roughness indices for each plot were calculated for each transect of the reliefmeter. These indices were used to study the effect of wetting/drying cycles on surface roughness by means of a SAS General Linear Models procedure.

Growth and Yield Analyses

Irrigation was applied twice daily, from planting until emergence was completed. Thereafter, irrigation was applied as needed. Additional nitrogen fertilizer (NH_4NO_3) was applied 21 and 34 days after planting (DAP) at a rate of 33 kg N ha^{-1} placed through the planting hole by hand.

Emergence. Emergence was measured daily starting 3 DAP. The number of emerging seedlings with cotyledons at least 45° apart was recorded daily, for 11 days, and a final count was made at 14 DAP. These data were used to determine total emergence (highest emergence value) and mean days to emergence (MDE). The latter is a measure of emergence rate, and was calculated using the following formula (Staub et al., 1986):

$$MDE = (E_iD_i)/T$$

where, T = total emergence; E_i = number of seedlings emerged on the ith day after planting and D_i = number of days after planting (DAP).

Thinning was performed 14 DAP, leaving one seedling per hole.

Transplants were grown in a greenhouse. Seedlings were transported to the field approximately 4 weeks after planting, and planted thereafter as soon as possible.

Flowering and yield. Date to 50% flowering was measured from days after planting (F_{50}) (Miller and Quisenberry, 1976).

Fruits from the center 3 m of the row on each plot were harvested, weighed, and classified according to the U.S. Standards for cucumbers. No peppers survived.

Results and Discussion

Surface Roughness

Water-drop impact caused by the irrigation sprinkler nozzles had no noticeable effect on the surface configuration. As the swollen large clods dried, they crumbled apart to form smaller clods, thus giving a smoother surface after each irrigation.

Whereas the amount of irrigation in consecutive wetting and drying cycles had an effect on R_f, in agreement with Dexter (1977), it did not affect R_b. Furthermore, the variation of R_b was at least 4 times that of R_f. The cloddy nature of the CPC at the time of bed formation and pressing resulted in a bed surface that was not horizontal. Therefore, the assumption of a horizontal surface for the calculation of R_b was proven to be invalid. Use of a

quartic regression equation to describe the existing bed surface allowed R_f to reflect the surface roughness presented to subsequent planting operations, and removed the effect of the underlying large clods.

The value of R_f taken at harvest (data not shown) was not different ($P>0.05$) from the initial preplant measurement (Fig. 5-2). As expected, the plastic covering precluded further mellowing by restricting the soil surface from drying. These findings agree with those of Dexter et al. (1984), who showed that increasing the number of wetting and drying cycles induced progressive mellowing. Subsequently, Pillai-McGarry and Collis-George (1990) reported laboratory evidence demonstrating that repeated wetting/drying cycles were an essential step in producing granular soil structure, rather than drying alone.

The surface roughness index, R_f, decreased with increasing irrigation volume in both seasons (Fig. 5-2). The r^2 range from 0.63 to 0.69 proved a cause and effect relationship, but suggested that other factors may have also influenced clod breakdown. The length of drying, coupled with related weather factors (such as the wind speed and duration, and temperature) could have also influenced R_f.

Allmaras et al. (1967) found that disking and harrowing reduced random roughness. Results of the present study showed a similar decrease through the imposition of wetting and drying cycles.

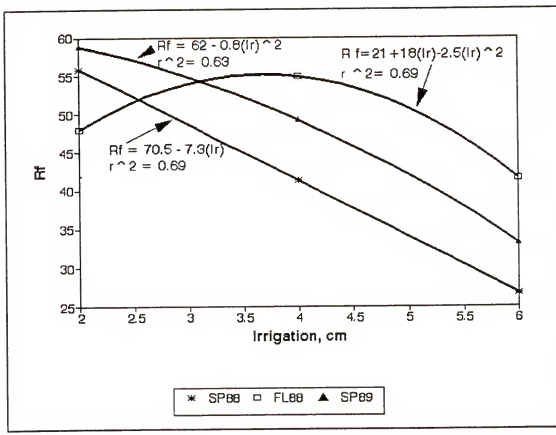


Figure 5-2. Regressions of Amount of Irrigation Water on Surface Roughness Coefficient, R_f, in a Cucumber Field Study at IMC Site, 1988-1989.

Growth and Yield Analyses

Since pepper did not produce marketable fruit, it was decided to change the crop to cucumber. Previously, González and Sartain (1985) had found that pepper did not grow well on CPC. The poor performance of pepper may be due to lack of aeration in the soil. Ferreyra et al. (1985) grew pepper on a Santiago loamy soil (coarse loamy over sandy skeletal, mixed, thermic Typic Xerocrept), and found that species to be highly susceptible to excess water in the soil. They found a yield decrease of 60% when water was applied in excess.

Surface roughness had no effect on growth or yield of cucumber. This result was expected, since the purpose of the surface roughness part of the study was to establish a relationship between surface roughness and wetting and drying cycles. The effect of seed cover, by contrast, was highly significant on both total emergence and MDE, during the Fall of 1988, but showed no effect during the Spring of 1989.

Emergence and Flowering.

Fall 1988. Emergence increased when seeds were suspended in plug-mix, or covered with LVM 6/30, rather than with screened CPC (Fig. 5-3). These results were found under conditions of high soil temperature that could cause plant stress. These findings agree with those of Perkins-Veazie et al. (1989) who found that those seed covers improved

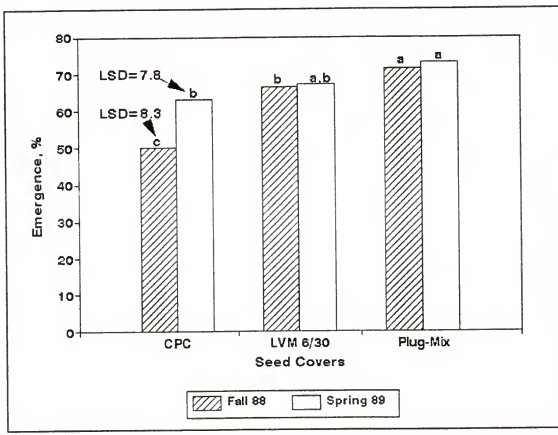


Figure 5-3. Effect of Seed Cover on Emergence of Cucumber, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Covers.

stands of cabbage (Brassica oleracea var. capitata) when average soil temperatures were at least 30 C.

During the final days of emergence, seedling population under CPC declined dramatically, due in part to a severe burning that killed the youngest seedlings. This burning was attributed to toxic compounds liberated to the atmosphere by the phosphate industry (stack emissions), although no measurements of toxic levels were available. The plantules grown in plug-mix were the least affected by this problem.

Spring 1989. In Spring 1989, when no effect of seed cover was found, wetter field conditions improved seedling emergence compared to Fall 1988 (Fig. 5-3). Total emergence remained about the same for seeds in plug-mix and LVM 6/30. However, emergence of seeds covered with screened CPC increased compared to Fall 1988 by more than 40%. The MDE in Spring 1989 was 1 d longer than in Fall 1988 (Fig. 5-4), and no significant difference was shown by any of the seed covers. The possible absence of temperature and moisture stress minimized the positive effect of plug-mix and LVM 6/30 covers. Furthermore, no stack emissions were observed from the surrounding industries.

The finer texture of plug-mix may have induced a better seed contact compared to the LVM 6/30. By contrast, possible crust formation due to partial drying of the CPC surface may have restricted seedling emergence. Royle and

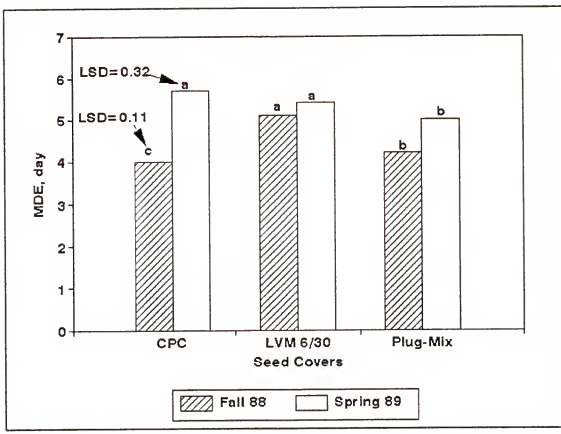


Figure 5-4. Effect of Seed Cover on Cucumber Duration to Emerge, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Covers.

Hegarty (1977) found that soil crusting delayed emergence of broccoli (Brassica oleracea var. italica Plenck.) seedlings by 2 to 7 days, decreased uniformity of emergence, and subsequent seedling growth.

Interpretation of the data (Fig. 5-3) suggested that emergence was related to water availability. Hot temperatures experienced during planting in Fall 88 caused plant stress. Therefore, the seed cover most able to supply water produced higher numbers of viable plants. This ability was in the order: plug-mix > LVM > CPC (Fig. 5-3). The number of wetting and drying cycles imposed at the beginning of the season had no effect on the number of days to reach anthesis (F_{50}). The planting method had an effect on F_{50} (Fig.5-4), although seed covers showed a similar value. The transplant treatment had at least 90% of its plants reach first flower 15 to 25 days before any direct seeding treatment. Direct-seeded plants took almost twice as long to flower. This observation is understandable, since transplants had enjoyed a highly favorable environment until transplanted.

Yield. Seed cover influenced all yield measurements under consideration (Fig. 5-5). No interaction effect of irrigation cycles with seed cover was found on the yield measurements. Hybrid Dasher II is generally harvested for the first time approximately 58 DAP (Hochmuth et al., 1988) when direct seeded. Harvest was initiated earlier with

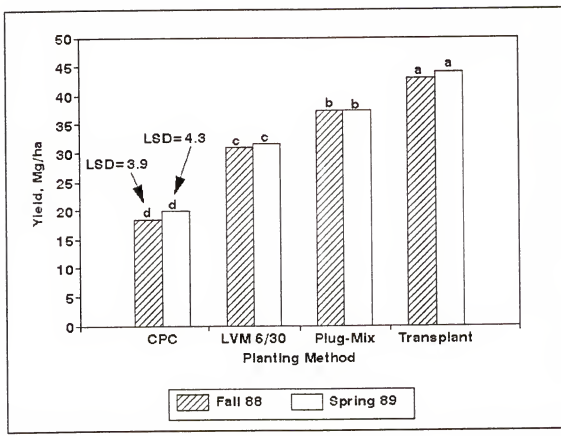


Figure 5-5. Effect of Planting Method on Cucumber Yield, IMC Field Study. LSD Comparison is Valid Within Season, Over Seed Cover.

transplants (38 DAP) than with direct seeded plants (56 DAP). These findings agree with those of Miller and Quisenberry (1976) who found that early anthesis is an important component of early maturity of cucumber. Yields in Fall 88 and Spring 89 were similar in magnitude. Yields exceeded Florida averages of 25.1 Mg ha^{-1} (Florida Agricultural Statistics, 1992) except for the CPC treatment.

Transplants produced higher yield (5.7 to 24.5 Mg ha^{-1} more) than any direct seeding method. The order of yield response to planting method was transplant > plug-mix > LVM 6/30 > screened CPC. The number of fruits showed a similar trend. Whereas the direct seeded plants had to endure unfavorable environmental conditions immediately after planting and emergence, the transplants were raised in an optimum, controlled environment. These conditions, maintained for 4 to 5 weeks before setting the seedlings in the field, gave the plants a head start. The plants were healthy and capable of resisting environmental stress.

The same trend for both seasons was also found for number of fancy fruits, total yield, and fancy yield. During the Fall of 1988, seeds planted in plug-mix produced the highest weight per fruit, and transplants produced the lowest; seeds covered with LVM 6/30 and CPC produced fruits of similar intermediate weight. During the Spring of 1989, the weight per fruit of seeds covered with screened CPC was similar to that of seeds planted in plug-mix.

Improved emergence in direct seeding induced higher yields. The plug-mix treatment produced the highest yield, followed by LVM 30. The lowest yields (about 2/3 of that produced by LVM 6/30) were obtained with the CPC treatment.

Conclusions

A relationship was found between the amount of irrigation (wetting and drying cycles) and R_f. It has been shown that increasing the number of wetting and drying cycles decreased R_f, improving seedbed surface conditions. The improved seedbed surface could be obtained through irrigation or by taking advantage of natural rainfall.

Transplanting or use of plug-mix seed cover allowed the production of cucumbers under the wide range of surface soil roughnesses included in this study. Transplanting appears to be the best option for cucumber production on CPC. However, an economic decision should be made considering the alternative of direct seeding with plug-mix. In either case, the expected yields on CPC exceed Florida average yields of cucumber.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The overall goal of this research project was to develop techniques that would enable farmers to manage reclaimed phosphatic clays for vegetable production. To accomplish this goal, greenhouse experiments were conducted in Gainesville growing snap bean on both fertilizer and MSS-amended CPC. Several experiments were conducted on recently reclaimed phosphatic settling ponds to monitor sweet corn performance, and to find the best management for seedbed preparation.

The CPC was found to contain low OC, but high levels of nutrients, with the exception of N (Chapter 2). Furthermore, CEC and base saturation were high. Application of N increased snap bean yield. It was found that snap bean required a source of N to grow on CPC. Three levels of P and K had no effect on the yield of snap bean. The results of this experiment confirmed that CPC provided all nutrients necessary for crop production, with the exception of N.

An anaerobically digested MSS provided N and OC to CPC (Chapter 3). An OC decomposition model successfully proved the long term effects of MSS on soil OC. No detrimental effect was found as a result of heavy metals on snap bean.

Addition of MSS enhanced the nutrient concentration of CPC. Application of MSS induced an increase in snap bean yield and plant growth. Foliar concentrations of nutrients increased, suggesting a higher availability. By contrast, heavy metals foliar concentrations were not affected, although they had been found to increase in the soil. The latter phenomenon suggests that heavy metals were sorbed to CPC, and that uptake per plant increased, but so did biomass yield, leaving concentration unaltered.

In summary, the results of the present study confirmed the hypothesis that CPC was a source of nutrients for snap bean. Furthermore, it was proven that MSS can provide N to snap bean grown on CPC, even at high rates (200 g MSS kg^{-1}) with no deleterious effects.

While the addition of low rates of MSS increased N and OC slightly in the soil, MSS had little effect on sweet corn nutrition or yield and quality. The rate of OC decomposition was higher under field conditions than that found under the glasshouse (Chapter 3). Changes in temperature and moisture in the field appear to have enhanced the decomposition of the materials. The composition of the material influenced the model, which was more sensitive to fresh material than to the more stable MSS. No harmful effects of MSS addition were found. Nutrition and fertility were not the controlling factors for sweet corn production on phosphatic clay.

Sweet corn cv. Merit can grow successfully on CPC. To produce corn or other vegetables in the area, wild animals should be controlled. Phosphatic clay can serve as a receptor for disposal of MSS, thus alleviating a municipal environmental problem, and improving the nutritive value of CPC.

An additional field experiment demonstrated a relationship between irrigation amount and surface roughness (R_f). Surface roughness analysis is a method that can be used to assess soil surface conditions. It has been shown that increasing the cycles of wetting and drying decreased surface roughness. Pepper did not grow on CPC during the one season in which they were planted. The experiment was continued using cucumber. Seed covers, especially plug-mix or LVM 6/30, allowed the production of cucumber under the wide range of surface soil roughness included in this study. Transplanting shortened the time to anthesis, reduced time to first harvest, and resulted in higher yields than any direct seeding method used in this study.

Recommendations for Follow Up.

Further study is warranted to assess OC decomposition rate on CPC, working on a simple incubation experiment to compare the decomposition of MSS on CPC and on surrounding unmined mineral soils. Furthermore, incubation studies will provide a better understanding of the kinetics of the system.

It was found that MSS rate influences the rate of OC decomposition; however, it is necessary to find out the long term effect that phenomenon will have on the release of nutrients and pollutants. The monitoring of water chemical composition in wells at different depths in the field would verify minimal movement of pollutants through the CPC profile. The results of an experiment like this would strengthen the value of reclaimed settling ponds as potential disposal sites for MSS.

In addition, microbiological studies will facilitate the understanding of the microbial population and activity on CPC, and the effects of sewage sludge application on microbial population and activity.

LITERATURE CITED

Akhter, M.S. 1990. Trace metal analysis of sewage sludge and soils in Bahrain. Water, Air, and Soil Pollut. 51:147-152.

Allmaras, R.R., R.E. Burwell, and R.F. Holt. 1967. Plow-layer porosity and surface roughness from tillage as affected by initial porosity and soil moisture at tillage time. Soil Sci. Soc. Am. Proc. 31:550-556.

Allmaras, R.R., R.E. Burwell, W.E. Larson, R.F. Holt, and W.W. Nelson. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Conserv. Res. Report No. 7. U.S. Govt. Printing Office, Washington, D.C.

Andersson, A., and K.O. Nilsson. 1972. Enrichment of trace elements from sewage sludge fertilizer in soils and plants. Ambio 1(5):176-179.

Ardaman and Associates, Inc. 1983. Evaluation of phosphatic clay disposal and reclamation methods. Vol. 4: Consolidation behavior of phosphatic clays. FIPR Pub. 02-002-008.

Asif, M.I., and J.K. Greig. 1972. Effects of seasonal interactions of nitrogen, phosphorus, and potassium fertilizers on yield and nutrient content of snap beans (Phaseolus vulgaris L.). J. Amer. Soc. Hort. Sci. 97:44-47.

Atlas, R.M., and R. Bartha. 1981. Microbial ecology: Fundamentals and applications. Addison-Wesley, Reading, MA.

Barwood, H.L. 1982. Mineralogy and chemistry of phosphatic clays. p. 30-41. In S.W. Clark (ed.) Phosphatic clay workshop. FIPR Pub. 02-020-012.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:363-375.

Bloomquist, D. 1982. Centrifuge modeling of a large strain consolidation phenomenon in phosphatic retention ponds. Ph. D. Dissertation, Univ. of Fla., Gainesville.

Blue, W.G., and P. Mislevy. 1982. Accelerated drying of the surface colloidal phosphate settling ponds from phosphate strip mining in Florida. Proc. Soil Crop Sci. Soc. Fla. 41:205-208.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-Total. In A.L. Page, R.H. Miller, and D.R. Keeney (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:595-624.

Bromwell, L.G. 1982. Physico-chemical properties of Florida phosphatic clays. FIPR Pub. 02-003-020. Bartow, FL.

Burnett, G. 1976. Phosphate lured the greedy, the untamed. Florida Trend 18(9):111-114.

Burwell, R.E., R.R. Allmaras, and M. Amemiya. 1963. A field measurement of total porosity and surface microrelief of soils. Soil Sci. Soc. Am. Proc. 27:697-700.

Burwell, R.E., R.R. Allmaras, and L.L. Sloneker. 1966. Structural alteration of soil surfaces by tillage and rainfall. J. Soil Water Cons. 21:61-63.

Burwell, R.E., and W.E. Larson. 1969. Infiltration as influenced by tillage-induced random roughness and pore space. Soil Sci. Soc. Am. Proc. 33:449-452.

Clapp, C.E., S.A. Stark, D.E. Clay, and W.E. Larson. 1986. Sewage sludge organic matter and soil properties. p. 209-253. In Y. Chen and Y. Avnimelech (ed.) The role of organic matter in modern agriculture. Martinus Nijhoff Publishers, Dordrecht, Neth.

Cheung, Y.H., and M.H. Wong. 1983. Utilisation of animal manures and sewage sludges for growing vegetables. Agric. Wastes 5:63-81.

Curtis, R.C., and W.D. Cole. 1972. Micro-topographic profile gage. Agric. Eng. 53:17.

Dexter, A.R. 1977. Effect of rainfall on the surface microrelief of a tilled soil. J. Terramechanics 14:11-22.

Dexter, A.R., B. Kroesbergen, and H. Kuipers. 1984. Some mechanical properties of aggregates of top soils from the IJsselmeer polders. 2. Remoulded soil aggregates and the effects of wetting and drying cycles. Neth. J. Agr. Sci. 32:215-227.

EcoImpact, Inc. 1980. A review of topsoiling suitability and feasibility for reclaiming phosphate mine soils in Florida. Report to International Minerals and Chemical Corporation, Bartow, FL.

Environmental Service Center. 1984. Phosphate mining in Florida: A source book. Florida Defenders of the Environment, Tallahassee, FL.

Farrah, H., D. Hatton, and W.F. Pickering. 1980. The affinity of metal ions for clay surfaces. Chem. Geol. 28:55-68.

Felton, G.K., and M. Ali. 1992. Hydraulic parameter response to incorporated organic matter in the B-horizon. Trans. ASAE 35:1153-1160.

Ferreyra E., R., G. Sellés van Sch., and J. Tosso T. 1985. Effect of different amounts of water applied to peppers. I. Effect of excessive soil humidity. Agric. Técnica 45:47-51.

Florida Agricultural Statistics. 1992. Vegetable summary. Fla. Agric. Stat. Ser. Orlando, FL.

Ford, R.D., J.M. Robbins, Jr., J.T. Werner, D. Cowherd, C.N. Gordon, W.B. Warmack, M.M. Brown, K.W. Monroe, W.G. George, T. Sanders, and P.M. Basch. 1990. Soil Survey of Polk County, Florida. Soil Conservation Service, USDA, in cooperation with Agricultural Experiment Stations and Soil Science Department of the Institute of Food and Agricultural Sciences, University of Florida, and Florida Department of Agriculture and Consumer Services. U.S. Govt. Printing Office, Washington, DC.

Garlanger, J.E., and F.N. Fuleihan. 1983. Reclamation options for clay settling areas. p. 33-59. In D.J. Robertson (ed.) Reclamation and the phosphate industry. FIPR Pub. 03-036-010. Bartow, FL.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agronomy 9:383-411.

González, R.X., and J.B. Sartain. 1985. Vegetable crop production on mixtures of Florida waste phosphatic clay and tailings sand. Soil Crop. Sci. Soc. Fla. Proc. 45:37-40.

González, R.X., J.B. Sartain, and W.L. Miller. 1992. Cadmium availability and extractability from sewage sludge as affected by waste phosphatic clay. J. Environ. Qual. 21:272-275.

Gough, L.P., H.T. Shacklette, and A.A. Case. 1979. Element concentrations toxic to plants, animals, and man. Geol. Survey Bull. 1466. U.S. Govt. Printing Office, Washington, DC.

Grace, H.T. 1954. A regional study of the phosphate industry. Florida Scientist 17(3):168-180.

Hanlon, E.A., and J.M. DeVore. 1989. IFAS Extension Soil Testing Laboratory chemical procedures and training manual. Univ. Fla. Coop. Ext. Serv. Cir. 812. IFAS, Univ. Fla., Gainesville, FL.

Harral, B.B., and C.A. Cove. 1982. Development of an optical displacement transducer for the measurement of soil surface profiles. J. Agric. Eng. 27:421-429.

Hawkins, W.H. 1973. Physical, chemical, and mineralogical properties of phosphatic clay slimes from the Bone Valley Formation. M.S. Thesis. Univ. Fla, Gainesville, FL.

Hayslip, N.C. 1973. Plug-mix seeding developments in Florida. Proc. Fla. State Hort. Soc. 86:179-185.

Hills, W.A., J.F. Darby, W.H. Thames, Jr., and W.T. Forsee, Jr. 1953. Bush snap bean production on the sandy soils of Florida. Univ. Fla. Agric. Exper. Sta. Bul. 530. Gainesville, FL.

Hinesly, T.D., L.G. Hansen, and G.K. Dotson. 1984. Effects of using sewage sludge on agricultural and disturbed lands. Project EPA-600/S2 83-113, USEPA, Cincinnati, OH.

Hinesly, T.D., and B. Sosewitz. 1969. Digested sludge disposal on crop land. J. Water Pollut. Control Fed. 41:822-830.

Hirschi, M.C., B.J. Barfield, I.D. Moore, and D.G. Colliver. 1987. Profile meters for detailed measurement of soil surface heights. Applied Eng. Agric. 3:47-51.

Hochmuth, G.J., E.A. Hanlon, and J.A. Stricker. 1987. Crop production on reclaimed phosphate-mined soils in Florida. HortScience 22:189-191.

Hochmuth, G.D., D. Maynard, W.M. Stall, and D.D. Gull. 1988. Cucumber production guide for Florida. Fla. Coop. Ext. Ser. Circular 101E. Institute of Food and Agricultural Sciences, Univ. Fla., Gainesville, FL.

Hochmuth, G.D., D. Maynard, C. Vavrina, and E. Hanlon. 1991. Plant tissue analysis and interpretation for vegetable crops in Florida. Univ. Fla. Coop Ext. Special Series SS-VEC-042. Institute of Food and Agricultural Sciences, Univ. Fla., Gainesville, FL.

Holtzclaw, K.M., D.A. Keech, A.L. Page, G. Sposito, T.J. Ganje, and N.B. Ball. 1978. Trace metal distribution among the humic acid and precipitated fractions extracted with NaOH from sewage sludges. J. Environ. Qual. 7:124-127.

Hsieh, Y.P., L.A. Douglas, and H.L. Motto. 1981. Modeling sewage sludge decomposition in soil. I. Organic carbon transformation. J. Environ. Qual. 10:54-59.

Hue, N.V. 1988. Residual effects of sewage-sludge application on plant and soil-profile chemical composition. Comm. Soil Sci. Plant Anal. 19:1633-1643.

Hue, N.V., J.A. Silva, and R. Arifin. 1988. Sewage sludge-soil interactions as measured by plant and soil chemical composition. J. Environ. Qual. 17:384-390.

Janssen, B.H. 1984. A simple method for calculating decomposition and accumulation of 'young' soil organic matter. Plant Soil 76:297-304.

John, M.K. 1972. Cadmium adsorption maxima of soils as measured by the Langmuir isotherm. Can. J. Soil Sci. 52:343-350.

Johnson, C.B., J.V. Mannering, and W.C. Moldenhauer. 1979. Influence of surface roughness and clod size and stability on soil and water losses. Soil Sci. Soc. Am. J. 43:772-777.

Joost, R.E., F.J. Olsen, and J.H. Jones. 1987. Revegetation and minesoil development of coal refuse amended with sewage sludge and limestone. J. Environ. Qual. 16:65-68.

Kelling, K.A., A.E. Peterson, L.M. Walsh, J.A. Ryan, and D.R. Keeney. 1977. A field study of the agricultural use of sewage sludge. I. Effect on crop yield and uptake of N and P. J. Environ. Qual. 6:339-345.

Kiemnec, G.L., D.D. Hemphill, Jr., M. Hickey, T.L. Jackson, and V.V. Volk. 1990. Sweet corn yield and tissue metal concentration after seven years of sewage sludge applications. J. Prod. Agric. 3:232-237.

Kuipers, H. 1957. A reliefmeter for soil cultivation studies. Neth. J. Agric. Sci. 5:255-267.

Lamont, W.E., J.T. McClendon, L.W. Clements, Jr., and I.L. Feld. 1975. Characterization studies of Florida phosphate slimes. U.S. Dept. Interior, Report of Investigation No. 8089. Washington, DC.

Lersch, G.A., F.D. Whisler, and M.J.M. Römkens. 1987. Soil surface roughness as influenced by selected soil physical properties. Soil Till. Res. 10:197-212.

Lersch, G.A., F.D. Whisler, and M.J.M. Römkens. 1988a. Spatial variation of parameters describing soil surface roughness. Soil Sci. Soc. Am. J. 52:311-319.

Lersch, G.A., F.D. Whisler, and M.J.M. Römkens. 1988b. Selection of a parameter describing soil surface roughness. Soil Sci. Soc. Am. J. 52:1439-1445.

Liang, B.C., and A.F. McKenzie. 1992. Changes in soil organic carbon after six years of corn production. Soil Sci. 153:307-313.

Low, P.F., and J.F. Margheim. 1979. The swelling clay: I. Basic concepts and empirical equations. Soil Sci. Soc. Am. J. 43:473-481.

McHardy, J.C. 1983. Future trends in Florida phosphate mining, beneficiation and tailing disposal. Mining Engineering 35:1196-1200.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Comm. Soil Sci. Plant Anal. 15:1409-1416.

Miller, J.C., Jr., and J.E. Quisenberry. 1976. Inheritance of time to flowering and its relationship to crop maturity in cucumber. J. Amer. Soc. Hort. Sci. 101:497-500.

Miller, R.H. 1974. Factors affecting the decomposition of anaerobically digested sewage sludge in soil. J. Environ. Qual. 3:376-380.

Million, J.B., R.X. González, W.D. Carrier, III, and J.B. Sartain. 1987. Production of vegetables on mixtures of sand tailings and waste phosphatic clay. p. 355-362. Proc. Symposium on Mining, Hydrology, Sedimentology, and Reclamation. Lexington, KY, 7-11 Dec. 1987. University of Kentucky, Lexington, KY.

Mislevy, P., and W.G. Blue. 1981a. Reclamation of quartz sand-tailings from phosphate mining: I. Tropical forage grasses. J. Environ. Qual. 10:449-453.

Mislevy, P., and W.G. Blue. 1981b. Reclamation of quartz sand-tailings from phosphate mining: III. Summer annual grasses. J. Environ. Qual. 10:457-460.

Mislevy, P., W.G. Blue, and J.B. Brolmann. 1981. Reclamation of quartz sand-tailings from phosphate mining: II. Forage legumes. J. Environ. Qual. 10:453-456.

Moore, I.D., and C.L. Larson. 1979. Estimating micro-relief surface storage from point data. Trans. ASAE 22:1073-1077.

Moorhead, K.K., D.A. Graetz, and K.R. Reddy. 1987. Decomposition of fresh and anaerobically digested plant biomass in soil. J. Environ. Qual. 16:25-28.

Mulchi, C.L., P.F. Bell, C. Adamu, and R. Chaney. 1987. Long term availability of metals in sludge amended acid soils. J. Plant Nutr. 10:1149-1161.

Mulchi, C.L., C.A. Adamu, P.F. Bell, and R.L. Chaney. 1991. Residual heavy metal concentrations in sludge-amended coastal plain soils - I. Comparison of extractants. Comm. Soil Sci. Plant Anal. 22:919-941.

Newborn, S. 1986. Profits could grow in mined out lands. The Tampa Tribune, Thur., 7 August, p. 2,4-Heartland.

Nicholaides, J.J., III, H.R. Chancy, L.A. Nelson, and J.E. Shelton. 1985. Snap bean grade and yield response to N rate and time of application and P and K rate. Comm. Soil Sci. Plant Anal. 16:741-757.

NOAA. 1988. Climatological data. Florida Section. U.S. Dept of Commerce, Ashville, NC. Vol. 94.

Patterson, D.E., W.C.T. Chamen, and C.D. Richardson. 1980. Long-term experiments with tillage systems to improve the economy of cultivations for cereals. J. Agric. Eng. Res. 25:1-35.

Peck, N.H., G.E. MacDonald, and A.V. Gardner. 1989. Snap bean plant responses to sources and rates of nitrogen and potassium fertilizers. HortScience 24:619-623.

Perkins-Veazie, P.M., D.J. Cantliffe, and J.M. White. 1989. Improved stand establishment of direct-seeded cabbage with seed covers. J. Am. Soc. Hort. Sci. 114:36-39.

Petruzzelli, G., G. Guidi, and L. Lubrano. 1985. Ionic strength effect on heavy metal adsorption by soil. Comm. Soil Sci. Plant Anal. 16:971-986.

Pillai-McGarry, U.P.P., and N. Collis-George. 1990. Laboratory simulation of the surface morphology of self-mulching and non self-mulching Vertisols. I. Materials, methods and preliminary results. Aust. J. Soil Res. 28:129-139.

Pittman, W.E., and J.W. Sweeney. 1983. A review of phosphatic clay dewatering research. Prepared for U.S. Dept. Interior, Bureau of Mines. FIPR Pub. 02-017-021. Bartow, FL.

Rahmani, M., T.G. Taylor, and D. Mulkey. 1990. An application of market window analysis: The case of vegetables grown on reclaimed phosphatic clay in Florida. Agribusiness 6:255-267.

Römkens, M.J.M., and J.Y. Wang. 1986. Effect of tillage on surface roughness. Trans. ASAE 29:429-433.

Royle, S.M., and T.W. Hegarty. 1977. Soil impedance and field emergence in calabrese. J. Hort. Sci. 52:535-543.

Sabey, B.R., and W.E, Hart. 1975. Land application of sewage sludge: I. Effect on growth and chemical composition of plants. J. Environ. Qual. 4:252-256.

SAS. 1988. SAS/STAT user's guide, release 6.03 Ed. SAS Institute Inc. Cary, NC.

Sauerbeck, D.R. 1991. Plant, element and soil properties governing uptake and availability of heavy metals derived from sewage sludge. Water, Air, and Soil Pollut. 57-58:227-237.

Scully, B.T., and D.H. Wallace. 1990. Variation in and relationship of biomass, growth rate, harvest index, and phenology to yield of common bean. J. Amer. Soc. Hort. Sci. 115:218-225.

Sims, J.T., E. Igo, and Y. Skeans. 1991. Comparison of routine soil tests and EPA method 3050 as extractants for heavy metals in Delaware soils. Comm. Soil Sci. Plant Anal. 22:1031-1045.

Smith, R.M. 1959. Some structural relationships of Texas blackland soils with special attention to shrinkage and swelling. Agr. Res. Ser., USDA. ARS-41-28. U.S. Govt. Printing Office, Washington, DC.

Sommers, L.E., C.F. Parker, and G.J. Meyers. 1981. Volatilization, plant uptake and mineralization of nitrogen in soils treated with sewage sludge. Purdue University Water Resources Research Center. Technical Report No. 133, West Lafayette, IN.

Sommers, L., V.V. Volk, P.M. Giordano, W.E. Sopper, and R. Bastian. 1987. Effects of soil properties on accumulation of trace elements by crops. p. 5-24. In A.L. Page, T.J. Logan, and J.A. Ryan (ed.) Land application of sludge. Food chain implications. Proc. Workshop USEPA, Cincinnati, OH. 13-15 Nov. 1985. Lewis Publishers, Chelsea, MI.

Soon, Y.K., T.E. Bates, and J.R. Moyer. 1980. Land application of chemically treated sewage sludge: III. Effects on soil and plant heavy metal content. J. Environ. Qual. 9:497-504.

Stafford, J.V., and B. Ambler. 1988. Seedbed assessment using video image analysis. ASAE paper No. 88-3541.

Staub, J.E., J. Nienhuis, and R.L. Lower. 1986. Effects of seed preconditioning treatments on emergence of cucumber populations. HortScience 21:1356-1359.

Stricker, J.A. 1987. Polk County Mined Lands Agricultural Research/Demonstration Project Final Report, First Year. Prepared for Florida Institute of Phosphate Research, Bartow, FL.

Stricker, J.A. 1988. Mine reclamation program deserves support from State. The Ledger, Fri. 16 September, p. 4B.

Tester, C.F., L.J. Sikora, J.M. Taylor, and J.F. Parr. 1977. Decomposition of sewage sludge compost in soil: I. Carbon and nitrogen transformation. J. Environ. Qual. 6:459-463.

Thomas, G.W. 1982. Exchangeable cations. In A.L. Page, R.H. Miller, and D.R. Keeney (ed.) Methods of soil analysis. Part 2. 2nd ed. Agronomy 9:159-165.

U.S. EPA. 1977. Municipal sludge management: Environmental factors. EPA 430/9-77-004. Office of Water Programs Operations, Washington, D.C.

U.S. EPA. 1993. Standards for the use or disposal of sewage sludge; final rules. Federal Register 58:9248-9415.

Van Ouwerkerk, C., M. Pot, and K. Boersma. 1982. Electronic microreliefmeter for seedbed characterization. Soil Till. Res. 2:81-90.

Vondrasek, A.F. 1982. Traditional land reclamation and waste clay storage method. p. 43-54. In S.W. Clark (ed.) Phosphatic clay workshop. FIPR Pub. 02-020-012. Bartow, FL.

White, W.A. 1970. The geomorphology of the Florida peninsula. Fla. Bur. Geo. Bull. 51. Tallahassee, FL.

Wollan, E., R.D. Davis, and S. Jenner. 1978. Effects of sewage sludge on seed germination. Environ. Pollut. 17:195-205.

Wolt, J. 1985. Utilization of organic wastes on agricultural soils of Tennessee. Agric. Expt. Sta. Bull. 638. Univ. Tennessee. Knoxville, TN.

Wong, M.H., W.M. Lau, and S.W. Yip. 1981. Effects of sludge extracts on seed germination and root elongation of crops. Environ. Pollut. Ser. A. 25:87-98.

Wood, C. 1986. Reclamation: Can agriculture fill economic vacuum created by Polk County's declining phosphate industry? The Citrus Industry 67:17-18.

Woods, C. 1986. Reclaiming phosphate mined lands for agriculture. Impact 3(1):12-13.

Xiu, H., R.W. Taylor, J.W. Shuford, and W. Tadesse. 1991. Comparison of extractants for available sludge-borne metals: A residual study. Water, Air, Soil Pollut. 57-58:913-922.

Zellars-Williams, Inc. 1978. Evaluation of the phosphate deposits of Florida using the minerals availability system. USBM - J0377000. U.S. Dept. Interior, Bureau of Mines, Washington, DC.

BIOGRAPHICAL SKETCH

Rafael Antonio Jerez y Gómez was born on 17 May 1949 in Manzanillo, a small town in the NW corner of the Dominican Republic (D.R.). He attended the Instituto Superior de Agricultura, in Santiago, D.R., where he obtained his high school diploma in agricultural sciences in 1967.

Rafael Antonio obtained the degree of Agrónomo from the Escuela Agrícola Panamericana (El Zamorano), Honduras, in 1970, and a certificate in photointerpretation applied to soil survey, from the Centro Interamericano de Fotointerpretación in Bogotá, Colombia, in 1976. He received B.S. and M.S. degrees in geography from the University of Florida in 1982 and 1985, respectively. He received an assistantship from the Soil Science Department to conduct research, funded by the Florida Institute of Phosphate Research in 1986 to pursue a Ph.D. program at U.F.

Rafael Antonio worked for the Secretariat of Agriculture of D.R. for twelve years, as an extension and soil conservation agent, first, and then as a soil surveyor. He is married to Dr. Nancy A. Durán de Jerez, and has two daughters, Geraldine Alexandra and Aída Esperanza. He will conduct research on forest wetlands management at U.F., as a postdoctoral associate.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Edward A. Hanlon, Chair
Associate Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Jerry B. Sartain, Cochair
Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Randall B. Brown
Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Donald A. Graetz
Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dorota Z. Haman
Associate Professor of Agricultural Engineering

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

George J. Hochmuth
Professor of Horticultural Sciences

This dissertation was submitted to the Graduate Faculty of the College of Education and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

April 1994

Jack L. Fry
Dean, College of Agriculture

Dean, Graduate School